# DECISION ANALYSIS USING VALUE-FOCUSED THINKING FOR INFRASTRUCTURE PRIORITIZATION

THESIS

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## Abstract

Infrastructure systems and facilities have deteriorated due to the impact of limited defense funding and competing priorities within the Air Force. The current method used for infrastructure prioritization is influenced by political sensitivity and uncertainty regarding the consequences of various funding decisions. Senior leaders need to better understand how their funding decisions will impact the overall condition and service life of the installation's infrastructure systems and facilities.

The purpose of this research was to improve the method of prioritizing infrastructure projects through the use of a decision analysis methodology known as Value-Focused Thinking. The value model was created based on the perspective of the civil engineer with inputs from a proxy decision maker at Headquarters Air Force Materiel Command. The model was used to apply three funding strategies to develop prioritized lists of restoration and modernization projects. It also applies metrics to compare the three funding strategies and their impact to the installation's infrastructure. The resulting model provides insight to the decision maker on which funding strategy is best suited for prioritizing infrastructure projects and how their selection of prioritized projects will impact the overall condition and service life of infrastructure systems and facilities.

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*To my parents*

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# I. Introduction

## 1.1 General Background

United States Air Force civil engineers have faced significant challenges in sustaining infrastructure systems throughout installations around the world. Since the early 1990s, as a result of constrained defense budgets and competing priorities within the Air Force, infrastructure systems have deteriorated due to the availability of funds to sustain these systems to meet mission requirements (Robbins, 2001). As one of the primary proponents for the maintenance and repair of these systems, the civil engineer has the responsibility to provide the decision maker(s) sufficient information to make informed selections regarding the distribution of these limited funds for infrastructure systems. Decision making in its basic state involves the selection between two alternatives. The Value-Focused Thinking (VFT) method is a step-by-step process that provides insight to the decision maker on the choice between multiple alternatives. The selection is based on what the decision maker values or considers relevant in making the decision.

VFT is used in this research to develop a model to aid a decision maker such as the installation commander or his or her representative in the selection of infrastructure

projects for funding. Based on the values of the decision maker, measures are then determined to assess those values. Each measure is then scored, and based on that total score, a recommendation is made. Using deterministic analysis and measures of effectiveness provides insight to the decision maker for selecting which infrastructure projects to fund.

## 1.2 Specific Background

Infrastructure systems have become an integral part of how we live, work and enjoy life on a daily basis. For our way of life to continue, these systems need to be adequately and continuously maintained. A broad definition of infrastructure is provided by Okada, Fang, and Hipel (2001:1211):

> …the entire set of basic and public availabilities (utilities) that support people's lives in a region, city, village or community. In general, infrastructure is immobile (locality-dependent) and has a long expected service life.

In this thesis, infrastructure is defined as bases, installations, real property, and their associated physical plants including buildings, utilities, runways, and other fixed structures.

In the private sector, the infrastructure is typically viewed as a capital asset; therefore, spending on infrastructure is seen as an investment. The opposite is true in the public sector where the tendency is to treat infrastructure systems as a liability (Toft, 1988:7). However, local governments are under increasing pressure to operate more like private industry in increasing efficiencies and productivity, while at the same time dealing

with challenges of being cost-effective, meeting technological advances, acquiring and retaining employees, and improving employees' work environments (Tabor, 2004:14).

Both sectors are continually challenged to adequately maintain their respective infrastructure systems, with the primary challenge often being limited funding. Inadequate funding is typically attributed to the lack of enthusiasm people tend to have towards maintenance and repair activities versus the natural excitement often associated with the construction of new facilities (Christian and Pandeya, 1997:53). Facility managers are the first to recognize that it is more cost effective to repair and maintain a facility or infrastructure system than to replace or rebuild it (Lyons, 2002:16). There is often a conflict between senior management and those that work directly with infrastructure systems on how much funding should be spent to maintain those systems (Christian and Pandeya, 1997:53).

Maintenance activities have typically been associated with the correction of existing problems instead of in a more proactive posture to prevent problems (Klusman, 1995:16). However, the impact of deferring maintenance can have unforeseen consequences. If the infrastructure is allowed to deteriorate until it becomes an emergency, it leads to increases in overall funding requirements and cascading failures caused by an increased load on other infrastructure elements to compensate for failures (McNeil et al., 1992:447). The impact of deferring maintenance can also be seen when the renovation a facility, or a building replacement, occurs much earlier than what would normally be projected for the typical lifespan of that facility (Lewis, 1991:495). Instead of deferring maintenance, the implementation of a preventive maintenance program can

result in significant cost savings, increased efficiencies and compliance of standards, and other improvements for an organization (Klusman, 1995:18). Figure 1 illustrates the conceptual view a facility's service life. Initially, the performance is shown below the optimum level due to the potential of the facility's design not completely fulfilling the user's requirements. Upon user adjustments, the building ideally reaches the optimum performance for a number of years with regular maintenance activities performed (Building Research Board, 1993:16). Over time though, the facility begins to deteriorate, and its function may potentially change; and as a result, the building's performance starts its decline. If adequate sustainment, restoration, and modernization are not performed, the facility's service life can decline to below the minimum level accepted by the user and require renovations or replacement (Installation Policy Board, 2001:2).

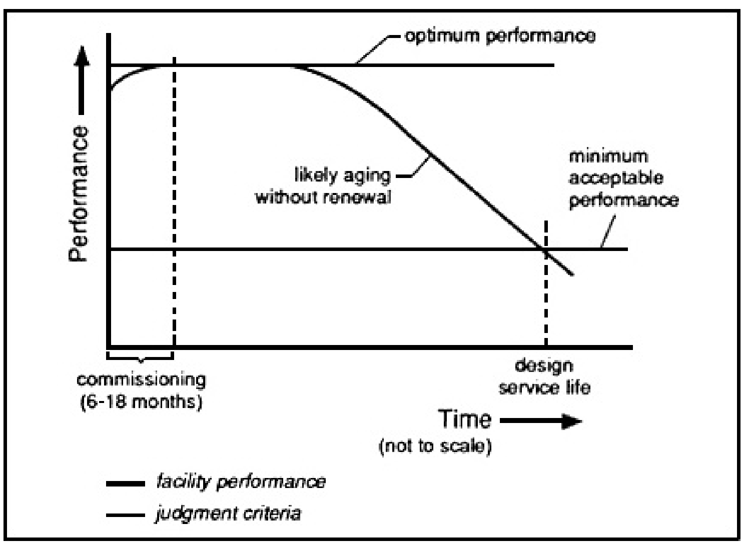


**Figure 1. Conceptual View of Lost Service Life Due to Insufficient Sustainment**
(Building Research Board, 1993:16)

In 2001, the American Society of Civil Engineers (ASCE) developed a report card in which it assigned an overall grade of “D+” to the nation’s infrastructure (ASCE, 2003:7). The ASCE followed up with a progress report in 2003 and showed the trend was not toward an improvement of the nation’s infrastructure (ASCE, 2003:7). The Department of Defense’s (DoD) infrastructure systems and facilities are also not faring much better. In the DoD, even though infrastructure obligations rose 26% between fiscal years 1998 thru 2001, spending on facility maintenance could not keep up with the rate of decline the facilities were experiencing and the competition for funding with other defense priorities (Rubin, 2003:12).

Throughout the Air Force, it is common for bases to face a tremendous backlog of infrastructure repair work in the hundreds of millions of dollars because senior leadership typically places a higher priority on funding new weapons systems and training rather than on infrastructure repair and maintenance projects (Cahlink, 2002). Subsequently, base civil engineers are often forced to delay the repairs for various infrastructure systems and facilities until the repairs become an immediate priority due to significant deterioration. This practice can become a cyclic problem that results in continued deterioration of infrastructure systems and facilities (Cahlink, 2002). In the Air Force, a startling example of its life-cycle assessment process is that it utilizes a 250-year replacement cycle for its facilities while civilian industries use a 50-year replacement life cycle (Ryan, 2000). Not repairing these deteriorated infrastructure systems and facilities can negatively affect the morale of Air Force personnel, thereby potentially impacting the retention of these airmen in the service (Cahlink, 2002). According to a report from the

General Accounting Office (GAO) released in February 2003, military officials have stated that 68% of facilities are so deteriorated that this inadequate infrastructure has affected the quality of life of military members and their families and also impacted the military members' ability to accomplish their mission (Rubin, 2003:12). Air Force Policy states that installation facilities and maintenance must be of "high quality" in order for the organization to appropriately operate and support its members (Department of the Air Force AFPD 32-10, 1999:1).

### 1.3 Research Problem

Air Force senior leadership is responsible for managing infrastructure systems and facilities at base installations. Therefore, they need an objective decision management tool that will allow them to ensure the Air Force's mission requirements, operations and maintenance goals are met while also effectively sustaining the infrastructure. This is a challenge to senior leadership due to the customary funding constraints that are presented for budgetary management and subjectivity placed during project prioritization.

### 1.4 Research Objective

The primary objective of this research is to develop a decision management tool that will enable senior Air Force leadership, henceforth referred to generically as the decision maker, to objectively evaluate which infrastructure system(s) should receive the necessary funding for restoration and/or modernization. This tool will also provide the capability of evaluating the impact of the selected projects on the overall condition and

service life of the installation's infrastructure. The development of this tool will be based on the hierarchy of operations and maintenance objectives articulated by Air Force policy.

### 1.5 Research Questions

There are three questions that will be investigated as part of this research effort. These questions are listed below.

1. What does the Air Force value in identifying which restoration and modernization projects to fund?

2. What is the impact to the overall lifespan and condition of infrastructure systems and facilities under various funding strategies?

3. What are the advantages and disadvantages to the new infrastructure prioritization tool versus that of the current Air Force method?

### 1.6 Research Approach

The research questions will be addressed by conducting a literature review that focuses on techniques used in the Air Force and industry for prioritizing infrastructure systems and facilities. After establishing the essential factors involved in the decision process, a decision management model will be developed to assist the decision maker in the prioritization of restoration and modernization projects. The model will be based on the "multiple objective decision analysis/value-focused thinking" concept using Logical Decision software. Value-focused thinking is a method of decision analysis that evaluates alternatives based on values applied to multiple, conflicting objectives and the selection of the best alternative toward meeting those objectives (Kirkwood, 1987:3).

Once the model has been developed, it will be implemented using real-world data collected from a base as a case study. The data will be comprised of an installation's restoration and modernization requirements for a given fiscal year. The results will be evaluated and recommendations will be developed from the data to provide alternatives to the decision maker.

## 1.7 Limitations

This research will focus specifically on how the Air Force determines which infrastructure system or facility projects to fund and how to improve the Air Force method of prioritizing infrastructure projects. In this thesis, the focus will be on restoration and modernization requirements. Private industry and public agencies to include those in the Department of Defense will serve as a comparison for infrastructure and facility management. However, the model may be of benefit to other military services depending on the criteria used in their decision-making.

In addition, since the value-focused thinking approach requires the utilization of a decision maker to define the weights of factors used in the model, there may be a certain bias associated with the model based on the input of that decision maker. This model will be developed from a civil engineer perspective as a tool to provide a recommendation to the base leadership. A "proxy decision maker" in conjunction with funding strategies will be used in lieu of a specific decision maker in this process. Nevertheless, the model should be flexible to adjust to any criteria or level of importance determined by any decision maker.

## 1.8 Review of Chapters

Chapter 2 consists of the literature review of infrastructure budget models and how various organizations prioritize their infrastructure projects for funding. It explains the current Air Force practice and how decision analysis can improve the process. This chapter also introduces two methods of decision analysis and explains why Value-Focused Thinking (VFT) is the appropriate method for this research. Chapter 3, Methodology, provides an overview of VFT prior to presenting the step-by-step process of creating the value hierarchy. Chapter 4 documents the results of the model along with the measures of effectiveness for the different funding strategies selected. Lastly, Chapter 5 summarizes this research and presents the benefits and limitations of the model and how it can be adapted. It concludes with recommendations for future research.

# II: Literature Review

## 2.1 Overview

The private and public sectors use several methods for managing their infrastructure systems and facilities. According to the National Cooperative Research Program, maintenance strategies that offer an inexpensive and immediate solution to an infrastructure issue can result in rapid decline and increased costs to fix the problem (Hastak and Baim, 1991:72). Based on budget models, various organizations have developed their own methods for prioritizing infrastructure projects to optimize their resources in order to maintain these systems. This chapter provides the background for this research. First, it presents the criteria and methods used for assessing and budgeting for infrastructure maintenance and repair requirements. Secondly, it presents infrastructure prioritization methods used by organizations and discusses in detail the Air Force's process for infrastructure prioritization. Thirdly, the concept of decision analysis will be introduced with a focus on the multiple-objective decision making method known as Value-Focused Thinking.

## 2.2 Infrastructure Budget Models

The following section presents the various methodologies reported in the literature that have been developed for managing infrastructure maintenance and repair requirements. There are various factors that influence the cost of operating and maintaining infrastructure systems; examples include infrastructure location, function,

size, and design; the type of material used to construct the infrastructure system; and the price index for utilities and services (Christian and Pandeya, 1997:52). Four broad categorizes for infrastructure maintenance and repair methodologies have been previously identified: plant value, formula-based, life-cycle cost, and condition assessment (Ottoman, Nixon, and Lofgren, 1999:72). Both private and public sectors use a range of these methodologies to determine their infrastructure requirements.

**2.2.1 Plant Value Methodology.** In the plant value methodology, maintenance and repair costs are determined as a function of the total construction or replacement costs for all facilities in the inventory (Ottoman et al., 1999:72). There are two ways to estimate this cost: current-plant value and plant-replacement value. Each method is based on the facility's cost and not the value of the property (Barco, 1994:30). The current-plant value (CPV) method is based on the initial construction cost of the facility, which is then adjusted to the current budget year (Barco, 1995:30). The use of the CPV is appropriate for facilities or systems whose current values accurately reflect the cost for the system's maintenance and repair costs versus the replacement value (Barco, 1995:31). If this is the case, the Building Research Board (1990) recommended that a factor of 2 to 4 percent of the current plant replacement value should be applied toward the budget of maintenance and repair of facilities (1996:1). Although the recommendation was supported by a number of facility managers, it was discovered that the policy was not widely implemented due to various factors including inconsistent interpretation of the guideline and implementation of the policy (Federal Facilities Council, 1996:2).

The plant-replacement value (PRV) model takes into account the type and use of a facility; it is typically calculated from the following equation (Barco, 1995:30).

$$PRV = FT * UC * GCI \tag{1}$$

where,

FT = facility type

UC = unit cost based on facility type

GCI = geographic condition index

This method plans for future funding availability for scheduled maintenance and repair projects.  Within the Department of Defense, the standard formula for plant replacement value is (Department of Defense UFC 3-7010-03, 2003:5):

$$PRV = FQ * CCF * ACF * HRA * PDF * SIOF * CF \tag{2}$$

where,

PRV = Plant Replacement Value

FQ = Facility Quantity

CCF = Construction Cost Factor

ACF = Area Cost Factor

HRA = Historical Records Adjustment

PDF = Planning and Design Factor

SIOF = Supervision Inspection and Overhead Factor

CF = Contingency Factor

The advantage of both methods is that they provide a relatively simple way to calculate maintenance and repair costs. However, a disadvantage to the CPV method is that the factor of 2 to 4 percent recommended by the Building Research Board does not allow agencies to catch up with the maintenance and repair requirements that have accumulated due to inadequate funding from previous years (Federal Facilities Council, 1996:15).

**2.2.2 Formula-Based Methodology.** Similar to the plant-based methodology described in the previous section, formula-based methods use a mathematical expression to determine the maintenance and repair requirements for a facility inventory (Ottoman et al., 1999:72). Sherman and Dergis (1981:21) assert that a good formula includes factors involving both the facility and the political environment where the decision for funding takes place. They developed an estimate for renewal costs based on the facility's age, building value at the current year, cost effectiveness of building renewal, and history of facility renovations. Sherman and Dergis (1981:23) developed a formula for the annual appropriation of facility:

$$2/3BV * BA/1275 \qquad (3)$$

where,

BV = building value

BA = building age

The first factor of 2/3 is based on the presumption that facility renewal should not cost more than two-thirds of what it would cost to construct an entirely new facility (Sherman and Dergis, 1981:22). The second factor of 1275 is formulated from a 50-year facility life-cycle and represents a weighted summation which serves to "skew fund generation for older structures." The factor 1275 is the summation of 1 through 50 for the expected life of a facility (Sherman and Dergis, 1981:22). Although the formula is based on a single facility, Sherman and Dergis (1981:24) recommend that the formula be used for a group of facilities instead of individually.

Phillips (1989:34) refined the Sherman-Dergis formula by developing renewal allowance formulas for facility systems and backlogs. For these formulas, major facility systems were categorized into either a 25-year or 50-year life-cycle. Examples of 25-year systems are the roof and heating, ventilation, and air-conditioning systems; examples of 50-year systems include exterior walls, partitions, conveying system, fixed equipment, fire protection, and electrical systems (Phillips, 1989:32).

$$\frac{\text{Renewal Allowance (50 - year systems)} = \text{BA} * RC\text{(50 - year system)}}{1275} \qquad (4)$$

$$\frac{\text{Renewal Allowance (25 - year systems)} = \text{BA} * RC\text{(25 - year system)}}{325} \qquad (5)$$

$$\frac{\text{Total Renewal Allowance (50 - year systems)} = \text{BA} * RC\text{(50 - year system)}}{1275} \tag{6}$$

$$\frac{\text{Renewal Backlog (25 - year systems)} = 1 + 2 + ... + \text{BA} * RC\text{(25 - year systems)}}{325} \tag{7}$$

$$\frac{\text{Renewal Backlog (50 - year systems)} = 1 + 2 + ... + \text{BA} * RC\text{(50 - year systems)}}{1275} \tag{8}$$

$$\begin{aligned}\text{Total Renewal Backlog} = \text{Renewal Backlog (25 - yr sys)} + \\ \text{Renewal Backlog (50 - yr sys)}\end{aligned} \tag{9}$$

where,

BA = Building Age

RC = Replacement Cost

Phillips (1989:36) also developed a formula to calculate the adjusted age of a facility based on facility renovations, the time since that renovation activity, and facility age.

$$\text{Adjusted Age} = \text{RF} * \text{YSR} + \text{UF} * \text{BA} \tag{10}$$

where,

RF = Renovation fraction

YSR = Years since renovation

UF = Unrenovated fraction

BA = Building Age

The benefits of using a formula-based approach include: it provides "reasonable, if not provable, algorithms to measured data," calculations are straightforward, and it is easy to comprehend and present to senior levels of management (Phillips, 1989:45). However, the formula-based approach does not provide a thorough and precise assessment of the facility (Phillips, 1989:42). It also does not account for the variety of building construction and size of facilities which makes generalizing the formula complex (Sherman and Dergis, 1981:22).

**2.2.3 Life-Cycle Cost Methodology.** Life-cycle cost analysis is considered a "future-oriented" methodology that is relatively young compared to the other methods used for infrastructure management (Arditi and Messiha, 1996:6). One reason that life-cycle cost methodology has not been widely adopted is that sufficient data has not been available to provide reliable estimates for life-cycle costs, particularly for new engineering concepts such as pre-stressed concrete (Arditi and Messiha, 1996:6). The life-cycle of a facility can be a function of how often maintenance is performed on the facility and the maintenance standard to which the facility is kept in good condition and operated (Novick, 1990:189). In addition, factors such as climate, construction material quality, and construction methods can also indirectly influence the use of life-cycle costing (Arditi and Messiha, 1996:6). During design and construction efforts, the attention given to required maintenance activities *a priori* can also significantly influence the overall maintenance and facility cost (Dunston and Williamson, 1999:57). The phases of a facility's life-cycle include "capital programming, concept study/alternatives analysis,

design and contract document preparation, construction, including management and inspection, operations, inspection and maintenance, repair and rehabilitation, and reconstruction, replacement, or divesting" (Novick, 1990:187). However, the only life-cycle phase evaluated in this research will be the operation and maintenance phase.

Determining life-cycles for buildings are different than other infrastructure systems such as transportation structures due to the fact that maintenance for most buildings are based on the building's subsystems such as the heating, ventilation, and air conditioning; plumbing; electrical systems; etc. (Corotis, 2003). Although the roofing system and building exterior require predictable maintenance, these systems are considered separate and independent of the building's structural system (Corotis, 2003).

The U.S. Army Construction Engineering Research Laboratory (USACERL) created databases to assist in predicting future annual life-cycle costs of facility maintenance based on various known factors to include square footage, facility use, and facility age (Neely and Neathammer, 1991:314). USACERL also developed a database to predict the total labor and equipment hours, as well as material and equipment costs, for each facility and for each trade when known combinations of factors have been provided (Neely and Neathammer, 1991:314). They categorized facilities into 34 groups based on the functional use of the facility. Through the creation of the database, USACERL developed a maintenance-resource-prediction model (MRPM) to predict requirements for 120 years of a facility's life-cycle.

**2.2.4 Condition Assessment Methodology.** A condition assessment is the technical evaluation of an infrastructure system's physical state. There are various ways to perform condition assessments based on the technology available to collect the data. Methods include visual surveys, as well as non-destructive and destructive inspections used to determine the integrity or degree of deterioration of the infrastructure system. Different factors can influence the cost and objectivity of the assessment to include the level of detail and frequency that assessments are accomplished, as well as who performs the evaluation and their degree of expertise (Uzarski and Lavrich, 1995:1637-1638). Condition assessments can also be subjective if the criteria to evaluate the systems are not standardized or specifically defined. In order to rate the condition of an infrastructure system, condition indexing is used by applying a value to the system (Chouinard et al., 1996:24). Projects are then prioritized for funding based on the infrastructure systems with the worst physical condition obtaining priority funding (Chouinard et al., 1996:24). Condition assessments typically require significant commitment of resources and time from the organization and are recommended more for smaller versus larger organizations (Sanford and McNeil, 1997:287). An example of a condition assessment tool is U.S. Army Builder, developed by USACERL. It is a database to prioritize facility projects based on the facility's current condition, available funding, and the remaining life of that facility/system (Hassanain et al., 2003:52). U.S. Army Builder provides a consistent and quick method to evaluate a facility's condition.

### 2.3 Budget Management Tools

Using a combination of the methodologies discussed, organizations have developed their own tools to budget their infrastructure requirements for repair and maintenance. Some budget management methods are the zero-based budget, project backlog budgeting, total maintenance and repair budgeting, Stanford model, and the macro-level methods used by the Department of Defense.

**2.3.1 Zero-Based Budgeting.** The zero-based budget method begins with a value of zero for each budget cycle and mandates that organizations provide primary and alternate programs for funding with justification for support (Wooldridge, Garvin, and Miller, 2001:88). This budget model is based on current year requirements versus using prior year requirements; it does not allow flexibility for other activities in the budget unless they are justified by need. The advantage to this budget method is that it clears the system inventory of projects that may no longer be valid; however, because there is no record of projects, it necessitates additional effort to compile the installation's new requirements.

**2.3.2 Project Backlog Budgeting.** The project backlog budget method is based on the backlog of unfunded facility projects. It designates projects to future budget years based on their priority (Barco, 1995:30). Prioritization of projects is based on assigning weights to various factors such as the facility, project, or occupancy type (Barco, 1995:30). The benefit of this model is that over time, projects can be completed or removed based on

combining requirements to complete a larger project or the lack of facility requirement (Barco, 1995:30).

**2.3.3 Total Maintenance and Repair (M&R) Budgeting.** The total M&R budget method is similar to the backlog budget method, but it is composed of scheduled maintenance and repair as well as deferred maintenance and repair projects (Barco, 1995:33). Deferred maintenance is defined as annual maintenance activities that are postponed due to funding or other constraints (Vanier, 2001:39). The total M&R budget is calculated as follows (Barco, 1995:33):

$$\text{Total M\&R Budget} = \frac{\text{\% of Total Facility Inventory PRV}}{\text{\% of Backlog}} \tag{11}$$

where,

PRV = Plant Replacement Value

The primary disadvantage of this method is that if it is not closely maintained, problems attributed to work safety and employee morale can arise (Barco, 1995:33).

**2.3.4 Stanford Model.** Huston and Biedenweg (1989:14) developed a facility management model to provide long-term infrastructure planning for the facilities at Stanford University. The mathematical model was based on facility type and facility subsystems; it included the costs and life-cycles of those subsystems and the age of the facility. Using experts, subsystem life-cycle estimates and costs were developed from

various construction cost indexes in comparison with Stanford's historical construction costs (Huston and Biedenweg, 1989:19). The significant result of this model was its ability to enable the university's administration to effectively manage its infrastructure assets by predicting funding requirements in future years and creating measures to meet those requirements (Huston and Biedenweg, 1989:29).

**2.3.5 Department of Defense Budgeting.** The Department of Defense (DoD) has attempted to make great strides to catch up with the level of maintenance and investment private industry has accomplished in terms of sustaining their infrastructure systems. In an effort to standardize and provide a common platform of information on infrastructure systems across the entire DoD, a database known as the Facilities Assessment Database (FAD) was created to capture all real property data (Installation Board, 2001:17). In addition, the Facilities Analysis Category (FAC) was created to ensure a common thread of the evaluation of each service's facilities. The FAC ensures that similar facilities and facility functions are under the same facility category between the services.

There are several macro-level budget models used in the DoD to determine the annual funding required to sustain each service's infrastructure through its normal life-cycle (Installation Board, 2001:18-19). The budget models also evaluate how the infrastructure is able to support each service's mission requirements. The methods presented are the Facilities Sustainment Model, Facilities Recapitalization Metric and Facilities Aging Model, and Installation Readiness Report under the Department of Defense Readiness Reporting System.

**2.3.5.1 The Facility Sustainment Model.** The Facility Sustainment Model (FSM) is a macro-level model intended for organizations above the installation and user level to identify annual sustainment requirements to support the physical plant throughout its normal life-cycle (Robison, 2004). The total sustainment cost is determined with the following equation (Robison, 2004):

$$\text{Total Sustainment Cost} = \text{Quantity} * \text{USC} * \text{ACF} * \text{Inflation} \tag{12}$$

where,

USC = Unit Sustainment Cost

ACF = Area Cost Factor

The model's unit and area costs are based on commercial standards (Robison, 2004). In order to feed into the FSM, each service has adjusted their previously unique data requirements to provide common information for maintenance and repair accounting (Infrastructure Board, 2001:24).

**2.3.5.2 Facilities Recapitalization Metric and Facilities Aging Model.** The Facilities Recapitalization Metric (FRM) tracks the restoration and modernization programs. It is a more accurate metric because it includes the combined impact of construction and other resources on the installation's facility inventory; it limits how recapitalized facilities are considered excluding single-use facilities and limiting the assets that other nations may use for recapitalization. The FRM is supported by the Facilities Aging Model (FAM). The FAM is a more detailed tool that allows evaluation

of what projects are needed for specific groups of facilities to maximize investment opportunities (Infrastructure Board, 2001:24).

**2.3.5.3 Installation Readiness Report.** The Installation Readiness Report is a report that each branch of service submits to Congress to identify how their infrastructure and facilities are able to meet support their mission requirements (Robison, 2004). C-ratings are determined for each facility class which parallel those identified in the Facility Investment Metric: operations and training; mobility; maintenance and production; research, development, training and education; supply; medical; administrative; community support; military family housing; dormitories; and utilities and ground improvements. The C-Rating is determined by dividing the total of all requirements by facility class divided by the plant replacement value of that class. Projects that are rated critical have a factor of five applied to the overall total, with degraded projects having an applied weight of three and essential projects weighted singly in the overall calculation shown below.

$$\text{C-Rating} = [(CR * 5) + (DR * 3) + (ER)]/PRV \tag{13}$$

where,

CR = Critical rated requirements

DR = Degraded rated requirements

ER = Essential rated requirements

PRV = Plant replacement value

The C-ratings are categorized as follows:

C-1 rating: If the percentage is less than 10 percent; there are that only minor deficiencies with negligible impact on capability to perform required missions.

C-2 rating: If the percentage is between 10 and 20 percent; there are some deficiencies with limited impact on capability to perform required missions.

C-3 rating: If the percentage is between 20 and 40 percent; there are significant deficiencies that prevent performing some missions.

C-4 rating: If the percentage exceeds 40 percent; there are major deficiencies that preclude satisfactory mission accomplishment.

The C-1 and C-2 ratings are for facility classes that meet the minimum standards, while C-3 and C-4 ratings are those facility classes which do not meet the minimum standards. Although there is a calculated C-rating value determined from the equation listed above, the Installation Commander also has the prerogative to upgrade or downgrade the C-Rating as well.

### 2.4 Infrastructure Prioritization Methods

This section presents infrastructure prioritization methods used by the U.S. Army and Air Force, respectively. The Army has created the Installation Decision Support Model, which is a highly interactive tool that allows senior leadership the capability to

compare several funding strategies and provides feedback about the results of the funding implementation. The Air Force uses a different approach with the application of the Facility Investment Metric to prioritize projects. The next sections will discuss the advantages and disadvantages of each prioritization process.

**2.4.1 U.S. Army Installation Decision Support Model (IDSM).** The IDSM model provides Army senior leadership the ability to develop infrastructure management goals with a prioritization system (Lind, Farr, and Kays, 1997:177). It also provides Army senior leadership the facility condition status and options for facility requirements, allows project selection within those requirements, describes how each facility project impacts management goals, and selects optimal projects to fund that will enhance meeting infrastructure management goal objectives (Lind, et al., 1997:177). Rather than have each stakeholder defend their facility project, IDSM provides objective guidance using computer support to provide the most appropriate guidance for the selection of infrastructure projects based on Army senior leadership goals (Lind, et al., 1997:178). IDSM also allows Army senior leadership to select from 12 funding strategies to create a prioritized list of projects which allows for comparing the effectiveness of those funding strategies (Lind, et al., 1997:178). It also provides feedback to Army senior leadership about the infrastructure's improvement, deterioration, funding, and the performance of that infrastructure based on the previous year's budget (Lind, et al., 1997:178). The advantage of the IDSM model is that it provides an objective process for Army leadership to prioritize projects for funding decisions as well as provide immediate feedback on the

impact of those decisions. However, Army condition assessments are extensive and the overall facility condition is based on the rating of each subsystem.

**2.4.2 Air Force Approach to Infrastructure Prioritization.** This section describes how the Air Force identifies and prioritizes infrastructure projects for funding. The Air Force incorporates two budget models toward managing its infrastructure requirements, the facility sustainment model (FSM) and the facility investment metric (FIM) (Robison, 2004). The requisite funding for infrastructure systems and facilities is divided into two different requirements: (1) sustainment and (2) restoration and modernization (R&M). Sustainment projects are defined as the recurring annual maintenance costs of facilities and infrastructure systems throughout their lifespan (Department of the Air Force AFI 32-1032, 2003: 20). Restoration projects include repairing or replacing facilities and infrastructure systems due to inadequate recurring maintenance and catastrophes or other causes (Department of the Air Force AF 32-1032, 2003:20). Modernization projects are described as those requiring modification of a facility or infrastructure system in order to comply with updated or greater requirements, providing new functions for organizations, or replacing facility elements that exceed 50 years of age (Department of the Air Force AF 32-1032, 2003:20). The primary difference between sustainment and R&M is that sustainment projects are funded primarily on an annual basis while R&M projects are funded based of inadequate sustainment to bring the infrastructure system back on its life-cycle track, catastrophic events, or other causes.

In order to prioritize restoration and modernization (R&M) projects for funding, the Air Force uses the Facility Investment Metric (FIM). The FIM is used at the installation level but is also understood at the corporate level (Robinson, 2004). It is the primary tool Air Force senior leaders use to identify facility requirements needed to meet the mission of the Air Force, so that decisions on key resources can be made. The FIM is used to prioritize projects based on the facility class and the effect on mission accomplishment if the project is not funded. The FIM includes only R&M projects that are funded through Operations and Maintenance (O&M) dollars. It does not include sustainment projects, designs, or studies or other funding accounts such as Military Family Housing, Defense Commissary Agency, or Environmental (Department of the Air Force AFI32-1032, 2003:37). This method also factors in the Installation Readiness Report, which each military service sends to Congress to describe the readiness of their installations and facilities.

Projects are typically ranked based on the facility class and installation/tenant mission impact (Department of the Air Force AFI 32-1032, 2003:38). Facilities are grouped into the following eleven main classes which are listed in order of priority ranking: operations and training; mobility; maintenance and production; research, development, training and education; supply; medical; administrative; community support; military family housing; dormitories; and utilities and ground improvements. The impact to the mission is based on the following categories: critical, degraded, and essential. The definitions of critical, degraded, and essential are as follows:

***Critical*** impact ratings are applied when projects meet the following requirements:

- Significant loss of installation/tenant mission capability and frequent mission interruptions.
- Work-arounds to prevent significant installation/tenant mission disruption and degradation are continuously required.
- Risk Assessment Code (RAC) 1.
- Fire Safety Deficiency Code (FSDC) 1.

***Degraded*** impact ratings are applied when projects meet the following requirements:

- Limited loss of installation/tenant mission capability.
- Work-arounds to prevent limited installation/tenant mission disruption and degradation are often required.
- RAC II or III.
- FSDC II or III.

***Essential*** impact ratings are when the following requirements are met:

- Marginal or little adverse impact to installation/tenant mission capability.
- Some work-arounds may be required.
- To prevent obsolescence.
- Any requirement which does not meet the Critical or Degraded criteria.
- Included in this rating category are requirements that would (1) improve the quality of life in work and living centers, (2) improve productivity and (3) lead to reduced operating costs (i.e., some facility consolidation and energy conservation initiatives).

The installation's facilities and infrastructure projects are prioritized at the Facility Board with the Facility Investment Metric (FIM) Requirements matrix, a two-dimensional layout of the facility class and impact rating. In addition to the matrix, the ability of each organization to increase the priority of their projects also influences the prioritization process. This reliance on organizational influences often leads to political sensitivities and makes it difficult to elevate the necessary projects that should be funded based on more pertinent FIM criteria. An example of this is provided by the Air Force Academy, where facility managers are known to spend their budgets on issues that are most visible to their customers. Although the customers appreciate the attention, less stress is placed on infrastructure elements that are not as visible (Thornton and Ulrich, 1993:45). Another limitation of the FIM is that the lifespan of a facility and infrastructure system are not included. Incorporating the element of life-cycle analysis can help forecast long-term requirements (Melvin, 1992:53). Lastly, the FIM method does not capture, or impart to the senior leaders, the effectiveness of implementing the prioritized infrastructure list on the condition and life-cycle of the installation's overall infrastructure.

| | IMPACT RATINGS | | |
|---|---|---|---|
| **Facility Class** | **Critical** | **Degraded** | **Essential** |
| **Operations and Training** | | | |
| **Mobility** | | | |
| **Maintenance and Production** | | | |
| **RDT&E** | | | |
| **Supply** | | | |
| **Medical** | | | |
| **Administrative** | | | |
| **Community Support** | | | |
| **MFH** | | | |
| **Dormitories** | | | |
| **Utilities and Ground Improvements** | | | |

**Figure 2. Facilities Investment Metric Matrix**

(Department of the Air Force AFI 32-1032, 2003:38)

## 2.5 Decision Analysis

Prioritizing infrastructure projects can be a difficult process because various objectives are typically required. Therefore, a decision analysis tool would be beneficial. Decision analysis enables decision makers to make informed selections based on a consistent and methodical approach to problem solving (Clemen and Reilly, 2001:4). Through decision analysis, insight into each element of the problem can be provided to the decision maker (Clemen and Reilly, 2001:4). Multiple-criteria decision making utilizes more than one objective to assess a problem (Ragsdale, 1997:805). This research will focus primarily on multiple objective decision analysis. The two methods for multiple objective decision analysis are alternative focused thinking and value focused thinking, which will be presented in the following sections.

**2.5.1 Alternative-Focused Thinking.** Alternative-Focused Thinking (AFT) is viewed as the typical and more reactive approach toward decision analysis (Kenney, 1992:47-49). As a decision maker, one may have the natural tendency to evaluate the solution to a problem by selecting from the best alternatives available versus considering the objectives to be accomplished (Kenney, 1992:47). Kenney (1992:49) states that through AFT, the decision process is more intuitive and limited because the new alternatives that are generated typically share common attributes with the original alternatives. The primary drawback with the AFT analysis is that it evaluates the benefit of one alternative in comparison with another instead of providing a solution to what the decision maker considers important toward solving the problem.

**2.5.2. Value-Focused Thinking.** Another decision analysis method is Value-Focused Thinking (VFT). VFT approaches the decision process by evaluating the decision opportunities versus alternative-focused thinking which considers decision problems (Kenney, 1992:47). This method assesses the values or factors of the problem that are important to the decision maker prior to evaluating the potential solutions (Kenney, 1992:50). There are many benefits to the VFT approach as illustrated in Figure 3.

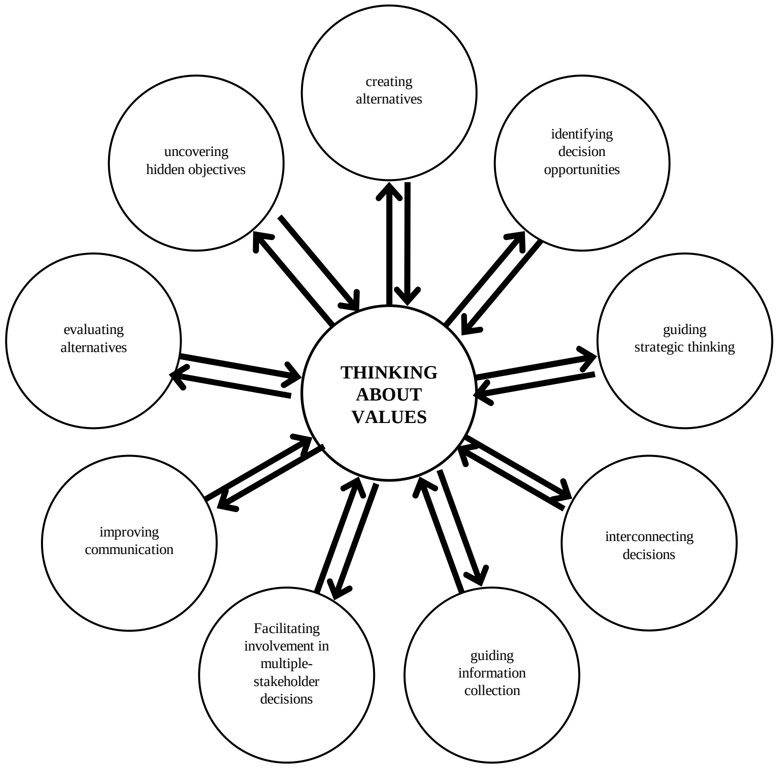


**Figure 3. Benefits of Value-Focused Thinking (Keeney, 1992:24)**

The VFT process begins with the decision maker identifying the specific problem. If there are also stakeholders involved, VFT can encourage discussion about the problem and the values or factors that are significant in the analysis (Keeney, 1992:25). This discussion can bring to light any potential value conflicts. Once the values are discussed and agreed upon, the values are weighted based on their importance to the decision maker. The values are then consistently applied to score the alternatives. As a result, a solution is generated from values significant to the decision maker versus the solution based on the best alternative. Insight is provided to the decision maker on the alternatives selected with deterministic and sensitivity analysis. The next chapters will present the

development of the value model using the 10-Step VFT process outlined by Shoviak (2001:63).

# III: Methodology

## 3.1 Overview

Selecting which infrastructure project to fund can be a difficult task because of the varying requirements put forth by both the stakeholders and the decision maker. Should the best infrastructure project to fund be prioritized based on the highest mission impact, least remaining lifespan, or highest project cost? These are just some of the conflicting objectives that the decision maker needs to consider when evaluating the best project to fund. The competing objectives in this research problem present an ideal scenario for the multiple-objective decision analysis process known as Value-Focused Thinking (VFT).

The VFT process uses factors that are not only important (i.e., of value) to the decision maker but are also easily measured and weighed in order of importance. The process provides the decision maker additional insight into the values of how the alternative(s) were determined. This chapter will present the development of the value model and will cover Steps 1 through 7 of the 10-Step VFT Process shown in Figure 5. Steps 8 and 9, which cover the results of the value model through deterministic and sensitivity analysis, will be discussed in Chapter 4.

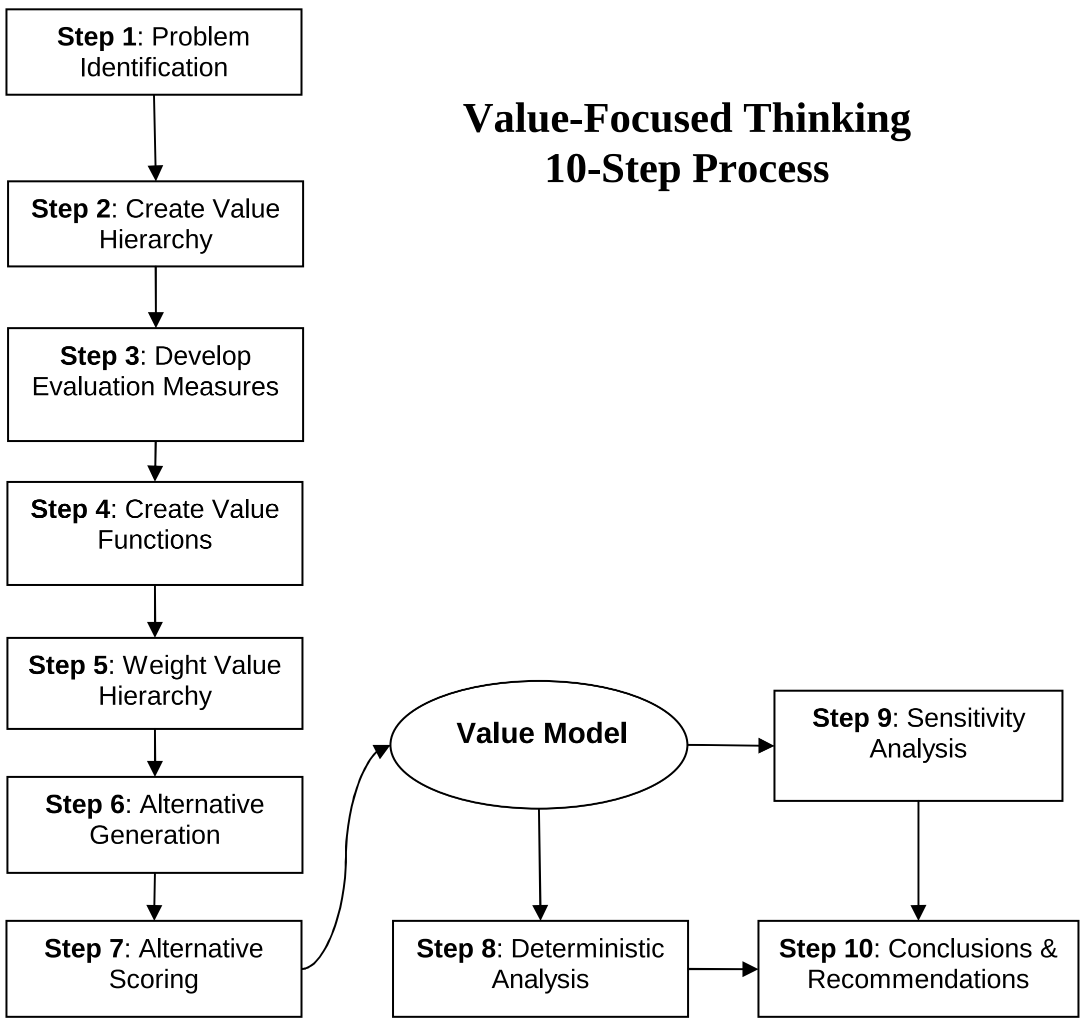


**Figure 4. Value-Focused Thinking 10-Step Process (Shoviak, 2001)**

## 3.2 Step 1: Problem Identification

The initial step in solving any problem begins first with identifying the problem to solve. The purpose of this research is to identify and present which infrastructure and facility project(s) to recommend for funding to the decision maker. The secondary purpose is to be able to illustrate the impact of the recommendations on the installation's overall condition status and lifespan of facility and infrastructure systems. The problem for this value model is which infrastructure system(s) should receive the necessary funding for restoration and/or modernization. The identification of these necessary infrastructure projects in a timely fashion will minimize infrastructure degradation and aid in sustaining these assets for the duration of their service life. Furthermore, it will ensure that the infrastructure will satisfactorily support the needs of the Air Force toward mission accomplishment.

## 3.3 Step 2: Constructing the Value Hierarchy

The value hierarchy is a graphical illustration and representation of the values that are significant in the decision making process. There are three standards typically used toward developing the value hierarchy: Gold, Silver, and Platinum (Weir, 2004). The Gold Standard uses a strategic objective(s), vision, plan, and other organizational guidance to identify the values pertaining to the fundamental objective. Even though the resulting value model can be constructed without direct input from the decision maker, its validity is based on the formal publications supported and enforced by the decision maker and organization. The Silver Standard relies on discussions with a group of stakeholders

in the decision process. Affinity diagrams are then used to document the input from the various stakeholders during the discussion sessions and then group the input into significant factors that form the value model. The benefit of using the Silver Standard is having group consensus in presenting the value hierarchy to the decision maker. It is a value model supported by all those involved and/or affected by the decision process. The last and highest standard is the Platinum Standard, which is based on direct input by the decision maker and/or senior leaders and key technical personnel regarding the identification of significant factors used to form the value model. As with the Silver Standard, the Platinum Standard uses affinity diagrams to develop a logical and simple value model.

The standard employed to develop this value hierarchy was the Gold Standard. However, due to the generalization of the value model, no specific decision maker was used. Instead, it is presented from the perspective of the base civil engineer. The Air Force Materiel Command Chief of Infrastructure and Facilities served as a proxy decision maker and provided direct inputs into the value model. The resulting hierarchy is relatively flexible in that it can be used by any decision maker at any installation. Although there is no direct input from the decision maker, the model is still valid because of the inputs of the proxy decision maker and the values used from and established by Air Force publications.

There are two approaches to constructing the value hierarchy: bottom-up and top-down structuring (Kirkwood, 1997:20). The bottom-up structure, also known as the "alternatives driven" approach, is appropriate if the alternatives are known. The

evaluation is thus based on how the alternatives differ (Kirkwood, 1997:20). Conversely, the top-down approach is better suited when the alternatives are not fully known at the beginning of the process (Kirkwood, 1997:20). This method begins with the fundamental objective and then uses an iterative process to identify important goals (i.e., values) essential toward evaluating the alternatives (Kirkwood, 1997:21).

The top-down approach was used for this research. Initially, a draft hierarchy was developed from Air Force guidance and policies. This "strawman" was then presented to the proxy decision maker and discussions were held to refine it. The resulting value hierarchy is shown as Figure 5. The top value in the hierarchy represents the fundamental objective which is to prioritize infrastructure projects. The values in the first tier are what the proxy decision maker considers important when presenting a recommended prioritized list from the civil engineer perspective to the decision maker. Figure 5 illustrates the first tier values which are attributes, cost, lifespan, and mission impact.

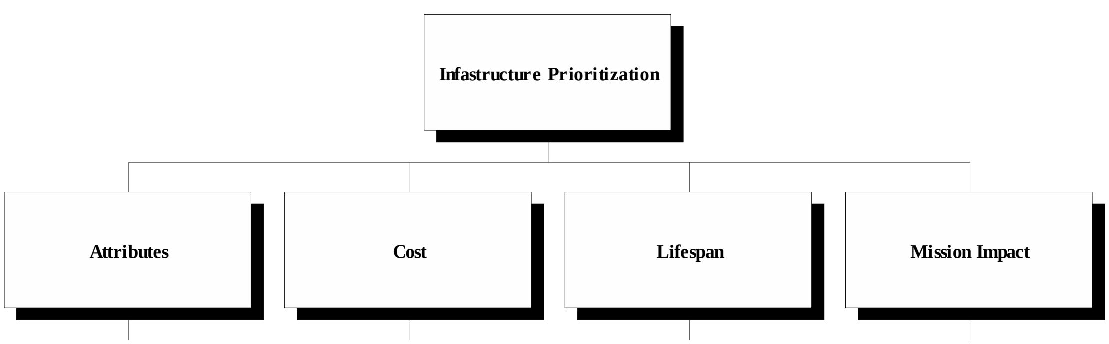


**Figure 5. First Tier Value Hierarchy**

The first goal shown in the value hierarchy is attributes. It describes the qualities that are important to the selection of the facility. The second goal is cost which is concerned about whether or not the investment is economically desirable. Lifespan, the next value in the hierarchy, describes how much longer the service life is of the facility. The last goal of the value hierarchy is mission impact which is a factor currently used in the Facility Investment Metric. It describes how the condition of the facility impacts the ability of the organization to fulfill its mission requirements.

Kirkwood describes five desirable properties of a value hierarchy: completeness, nonredundancy, decomposability or independence, operability, and small size (1997:16). Completeness of a value hierarchy ensures that all relevant concerns and issues needed to evaluate the objective of the hierarchy are included or assessed for potential inclusion (Kirkwood, 1997:16). Nonredundancy simply implies that no two values or measures are overlapped in a tier or within the overall hierarchy. The effect of overlapping causes a particular value to have a higher weighting and impact in the evaluation of the overall alternative than what was probably intended when weights were assigned to the values (Kirkwood, 1997:17). Completeness and nonredundancy requirements of the model can be generalized in the statement of being "mutually exclusive and collectively exhaustive" (Kirkwood, 1997:17). The next property of concern is decomposability or independence which ensures that a value in a tier is not dependent upon another level or tier (Kirkwood, 1997:18). Operability is determined by how understandable the value model hierarchy is to the user (Kirkwood, 1997:18). If there are certain values or measures that are difficult to understand, adjustments should be made to value hierarchy (Kirkwood, 1997:18).

Lastly, the size of the value hierarchy can be a factor in communicating the values and measures to the decision maker or users of the model. A small size may lead to less complexity in the model and add to the model's understandability and comprehension by those using it (Kirkwood, 1997:19). If the model is too complex, the values in the hierarchy might be too diluted to show significance in evaluating the alternatives (Kirkwood, 1997:23). A complex model usually requires more resources to collect data and evaluate the alternatives; therefore, the reliability of the model from the perspective of the decision maker might decrease (Kirkwood, 1997:23). Additionally, model complexity may inhibit the use and implementation of the model by the decision maker.

### 3.3 Step 3: Development of the Evaluation Measures

The factors considered to determine the evaluation measures for the value include similar factors in the literature, sponsor concerns, usability, and data availability. Evaluation measures enable an alternative to be scored with respect to meeting the objective of the value hierarchy (Kirkwood, 1997:24). Evaluation measures can be classified by four different scales: natural or constructed and direct or proxy. The evaluation measures can be developed in any of the following combinations: natural-direct, natural-proxy, constructed-direct, and constructed-proxy.

A natural scale is defined as a measure that has a common definition and interpretation to the general public (Kirkwood, 1997:24). An example of a natural scale would be the age of a person. A constructed scale is used when a natural scale cannot be determined; it provides a reasonable alternate method for evaluation (Kirkwood,

1997:24). The level of security is an example of a constructed scale. The natural scale is typically easier to define than a constructed scale. A direct scale exactly assesses how a measure is scored toward meeting the objective, while the proxy scale uses an associated method to assess how a measure meets the objective (Kirkwood, 1997: 24-25). According to Kirkwood (1997: 28), all measures should be able to pass the clairvoyance test: if a clairvoyant were able to predict the future, would he or she be able to assign a score to the outcome for each alternative evaluated in a decision problem (Kirkwood, 1997:28). The value hierarchy for this model uses all combinations of the scales: natural-direct, natural-proxy, constructed-direct, and constructed-proxy. The respective measures are shown in the value hierarchy at Figure 6 and discussed in the following sections.

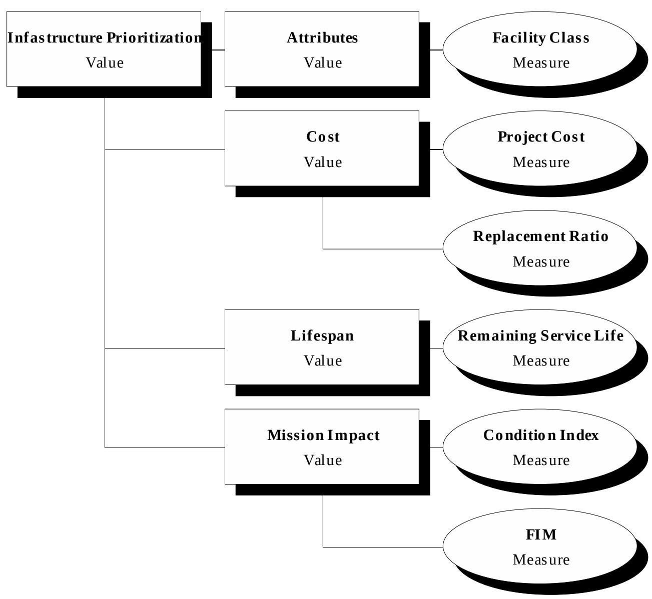


**Figure 6. Final Value Hierarchy for Infrastructure Prioritization**

**3.3.1. Measures Considered for Use in the Model .** Based on the literature review of various budget models and discussions with the proxy decision maker, several factors were considered for possible inclusion in the VFT model: facility class, type of construction, system type, complexity of facility, size of facility, facility's use, condition rating, facility investment metric, level of facility maintenance, environmental compliance and assessment program finding, cost, replacement ratio, subsystem cost and subsystem replacement ratio, remaining service life, repair type and remaining subsystem service life. Several measures were not included due to availability of the data in the Air Force civil engineer database known as the Automated Civil Engineer System (ACES) as well as because of discussions with the proxy decision maker to maintain model usability and simplicity.

Under the value of facility attributes; facility class, type of construction, system type, complexity of facility, size of facility, and facility's use were evaluated. The system type and the size of facility were factors that were available in the ACES database but were deemed as factors that would not be important discriminators required to elevate one facility versus another in prioritization for project funding. The type of construction and complexity of the facility were also not considered important factors. Facility use was considered an important value but is included in the facility investment metric measure of facility class. Therefore, to include facility use would be a redundant factor and not meet the requirement of the measures to be mutually exclusive.

In the assessment of the cost value; project cost, replacement ratio, and subsystem cost/ratio were evaluated. For model simplicity, subsystem cost and the subsystem

replacement ratio were not included. The subsystem cost can sometimes be the same as the project cost depending on what is accomplished in the project. The subsystem replacement ratio's exclusion is also justified for the same reasons of subsystem cost. Furthermore, the determination of the subsystem cost and replacement ratio can be time intensive to track and record separately; therefore, they were not included.

In the next value of lifespan, the measures of remaining service life, repair type, and remaining subsystem service life were evaluated. The repair type, and remaining subsystem service life were factors not included in the value model. The repair type which refers to replacement or repair, was not incorporated because the method by which a project gets completed was not considered an important factor toward elevating it for funding prioritization. The remaining subsystem service life was also not included in the value model due to redundancy when the overall facility's replacement ratio is also being considered.

When assessing the last value of facility condition; the condition rating, facility investment metric (FIM), the environmental compliance and assessment program (ECAMP) finding/Notice of Violation (NOV), and level of maintenance were all factors considered. However, the ECAMP finding/NOV was not included in the value model as a measure because it is an external factor that does not impact the physical condition of the infrastructure and would get immediate funding if necessary. The level of maintenance was also not included as a measure because it can be indirectly measured in the remaining service life with the adjusted age calculation. The adjusted age calculation

considers the how often and what type of maintenance was accomplished for an infrastructure system or facility.

**3.3.2 Facility Class.** Facility class is determined directly by the category code, function and/or mission of the particular facility or infrastructure system; it is also one of the primary determinants for prioritizing projects under the current Facility Investment Metric. There are 11 possible facility classes; however, the scope of this research is on restoration and modernization projects within the operations and maintenance funding parameter; therefore, the facility classes of medical, military family housing, and dormitories were excluded as they have separate funding requirements. The eight remaining facility classes used in this research are prioritized in the following order: operations and training; mobility; maintenance and production; research, development, training, and education (RDT&E); supply; administrative; community support; and utilities and grounds improvement. The priorities of the facility classes parallel the Air Force Infrastructure Investment Priorities (Air Force Handbook 108$^{th}$ Congress Air Force, 2003:13).

1. Beddown of new missions and weapon systems supporting transformation.
2. Fact-of-life requirements (i.e., project planning and design, emergency construction requirements, legal and treaty requirements).
3. Quality-of-life facility investments (i.e., dormitories, fitness centers).
4. SECAF, CSAF, Major Command Commander highest priorities.

**3.3.3 Condition Index.** The condition index evaluation measure is defined as the physical rating or state of defect for a facility or infrastructure system. The infrastructure condition index standard determines the requirements for each installation and provides adequate funding for systems evaluated on a systematic basis to ensure that facilities and infrastructure systems are maintained at the preventative maintenance level (AFMC, 1997:1). The condition index ranges from a value of 10, which indicates a new condition, to a rating of 0, which suggests a system failure (AFMC, 1997:A-4).

**3.3.4 Facility Investment Metric.** The facility investment metric (FIM) is one of the primary factors used by the Air Force during the prioritization process for projects. It describes the impact of a facility's state of repair on the organization's mission. It is also comprised of the Fire Safety Deficiency Code (FDSC) assessed by the Fire Department and/or the Risk Assessment Code (RAC) assessed by Safety. The FIM is prioritized under the three elements of critical, degraded or essential categories previously discussed in Chapter 2.

**3.3.5 Remaining Service Life .** The remaining service life measure is the years that are left for a facility or infrastructure system's estimated finite lifespan. It is calculated using Phillips's (1989:36) adjusted age formula for an infrastructure system. The adjusted age formula accounts for the amount of annual maintenance performed on that system.

$$\text{Adjusted Age} = RF * YSR * UF * BA \tag{14}$$

where,

RF = Renovation fraction

YSR = Years since renovation

UF = Unrenovated fraction

BA = Building Age

The renovation fraction in this evaluation measure was determined from the component weightings for systems provided by the AFMC Infrastructure Condition Standards (AFMC, 1997:A-1). The remaining service life is calculated using Phillip's adjusted age subtracted from 67 years. Although, the current facility recapitalization rate is 200 years, DoD is working to reduce it to 67 years as illustrated in Figure 7, to be more comparable to the commercial sector (Installations Policy Board:3).

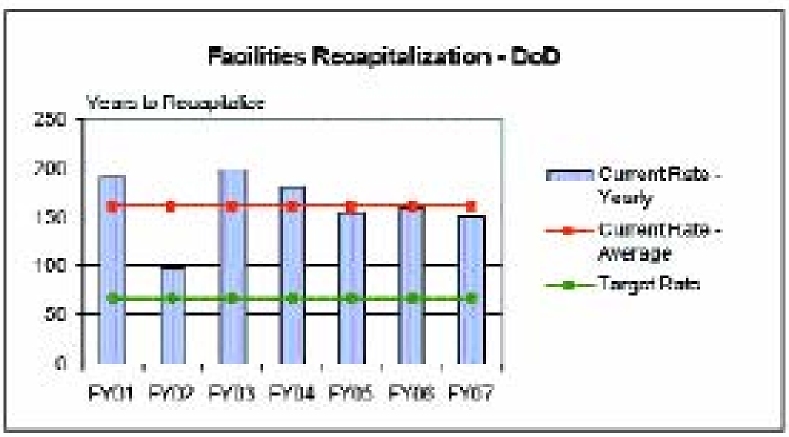


**Figure 7. Recapitalization to Counter Obsolescence**
(Installations Policy Board, 2001:3)

**3.3.5 Project Cost.** The project cost measure is defined as the construction cost of the project. It is significant to the decision analysis because there are times when the decision maker may want to accomplish more projects with the available funding. A higher project cost can severely limit the number of remaining projects that can be funded. The proxy decision maker wanted to place more value on projects with lower costs than those with higher costs.

**3.3.6 Replacement Ratio.** The replacement ratio measure is defined as total project cost divided by the replacement cost. It is calculated according to the following formula:

$$\text{Replacement Cost Ratio} = \frac{\text{Project Cost}}{\text{Plant Replacement Value}} \tag{15}$$

If a proposed repair exceeds 70 percent of a facility's replacement cost, an economic analysis must be accomplished indicating that a repair is more cost effective than the construction of an entirely new facility (Department of Defense AFI 32-1032, 2003:17). The assumption made for the alternatives (projects) provided are that the cost of facility repairs does not exceed the replacement cost of the facility. However, there may be some projects that will maximize this utility value based on the estimates entered in the Automated Civil Engineer System.

### 3.4 Step 4: Creating the Value Functions

The single dimension value function allows for the evaluation measure to be scored on a common scale. It establishes a uniform method for rating each of the evaluation measures and converts it to a unitless scale (Kirkwood, 1997:60). Kirkwood identifies two types of functions for the single dimension value functions: piecewise linear and exponential (1997:61). He also recommends that the piecewise linear scale be used when the evaluation measure has a small number of potential scoring levels (Kirkwood, 1997:61). Single dimension value functions (SDVF) can either be monotonically increasing or decreasing, with the scale on a *y*-axis ranging from 0 to 1. In Figure 8, project cost is shown as a monotonically decreasing function.

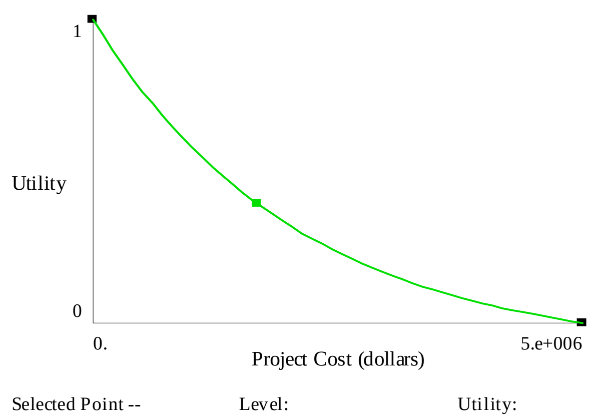


**Figure 8. Monotonically Decreasing Exponential SDVF for Project Cost**

If the value of an evaluation measure is preferred to be monotonically increasing, then the exponential single dimension value function is recommended (Kirkwood, 1997:65). Kirkwood presents the exponential single dimensional value function in the following equation (1997:65):

$$v(x) = \begin{cases} \dfrac{1-\exp[-(x-Low)/\rho}{1-\exp[-(High-Low)/\rho]}, & \rho = \text{Infinity} \\[2ex] \dfrac{x-Low}{High-Low}, & \text{otherwise} \end{cases} \tag{16}$$

where,

x = the evaluation measure

ρ = exponential constant

Low = the lowest level of the evaluation measure

High = the highest level of the evaluation measure

The shape of the exponential function is determined by the proxy decision maker. Through the use of the Logical Decision software, the exponential constant can be determined from fitting the curve to designated points on the graph (Weir, 2004). The most common types of curves are linear, concave, convex, and s-curve (Weir, 2004).

Another type of single dimensional value function (SDVF) is categorical. The categorical SDVF is used for the evaluation measures with a smaller amount of values. A

project can fall into one of the eight facility classes listed in the SDVF shown in Figure 9. The values were distributed with the most preferred score based on the priority ranking of facility classes under Air Force requirements. The decision maker also has the flexibility to apply more weight to focus on a specific facility class if that is what he or she desires. The remaining single dimension value functions for the other measures are shown in Appendix B.

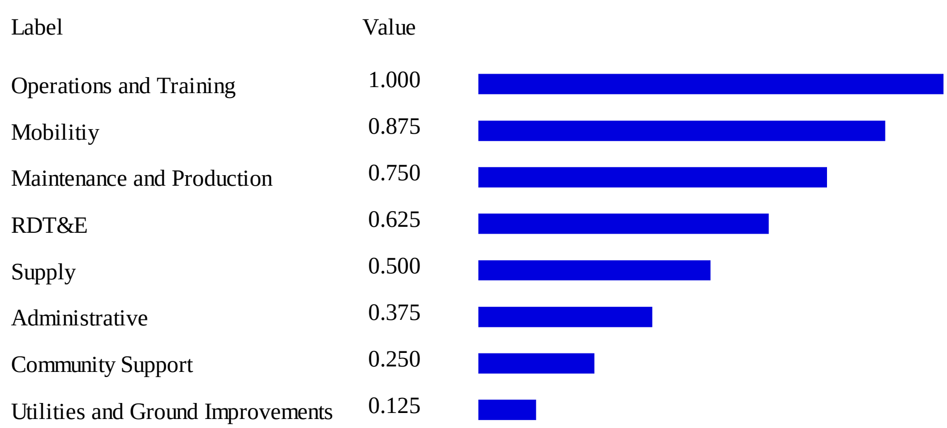


**Figure 9. Categorical Value Function for Facility Class**

### 3.5 Step 5: Weighting the Value Hierarchy

The purpose of weighting the hierarchy is to apply priorities to the evaluation measures that reflect the importance of each value to the decision maker. There are two ways to look at this prioritization process: local and/or global weights. The local weights are determined by examining only the values within the same tier of a branch; the local

weights must sum to one.  Global weights are determined by examining all of the values on the same tier across all branches in the hierarchy:  the global weights on any tier must also sum to one.  The global weights display how much a particular value contributes to the overall value of an alternative.

There are two ways to determine the local weights of a value hierarchy:  swing weights (or value increment procedure) and the group weights procedure.  The swing weights method begins with the evaluation measures placed from the least to greatest value.  Each measure is then represented as a multiple of the least value measure (e.g., 2:1, 10:1, or 4:1).  All weights are then summed to one and the resulting equation is solved for the weight of the least valued measure.  In the group weight method, 100 points are distributed among the values considered on the same tier across the all branches.  The weights are simply the number of points divided by 100.  If there are any significant differences of opinion, points may be redistributed until there is group consensus (Weir, 2004).

Rather than have a decision maker or the proxy decision maker apply their subjective weighting desires to the value hierarchy, a hypothetical weighting scheme was applied to reflect three funding strategies:  overall improvement of facilities by class, overall improvement of facilities by condition, and minimization of facility degradation of service life.  The weightings for each funding strategy were determined using the swing weight procedure.

For the first funding strategy (overall improvement by facility class), cost was determined to be the smallest value increment.  The other evaluation measures were

weighted in proportion to cost as shown below. The equations were then summed to one to determine their local weights in the hierarchy; in this case, the local weights are also the global weights. The weighting proportion for measures within a branch was equally divided. The resulting weights are shown in Figure 10.

$w_{cost}$ = value of least importance
$w_{lifespan} = 3 * w_{cost}$
$w_{mission\ impact} = 5 * w_{cost}$
$w_{attributes} = 8 * w_{cost}$
$w_{cost} + w_{lifespan} + w_{condition} + w_{attributes} = 1$
$w_{cost} + 3w_{cost} + 5w_{cost} + 8w_{cost} = 1$

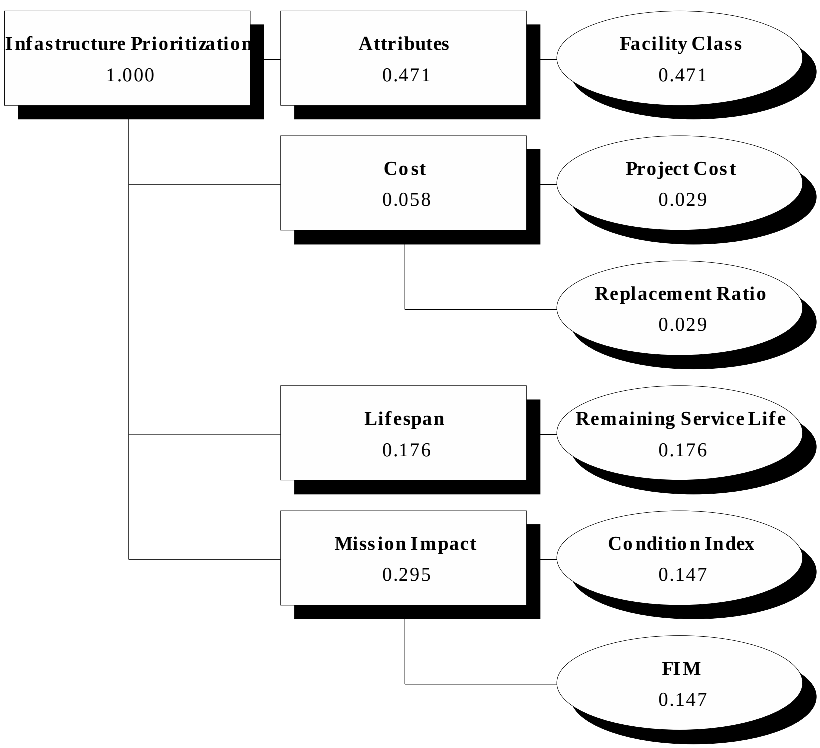


**Figure 10. Global Hierarchy Values for Overall Improvement of Facilities by Class**

For the second funding strategy (overall improvement of facilities by condition), cost was again determined to have the least importance. The remaining values were weighted in proportion to cost as shown below. The equations were then summed to one to determine their local weights in the hierarchy; as before, the local weights are also the global weights. The measures under cost and mission impact were equally weighted within the branch. The resulting weights are shown in Figure 11.

$w_{cost}$ = value of least importance
$w_{attributes} = 3 * w_{cost}$
$w_{lifespan} = 5 * w_{cost}$
$w_{condition} = 8 * w_{cost}$
$w_{cost} + w_{attributes} + w_{lifespan} + w_{condition} + = 1$
$w_{cost} + 3w_{cost} + 5w_{cost} + 8w_{cost} = 1$

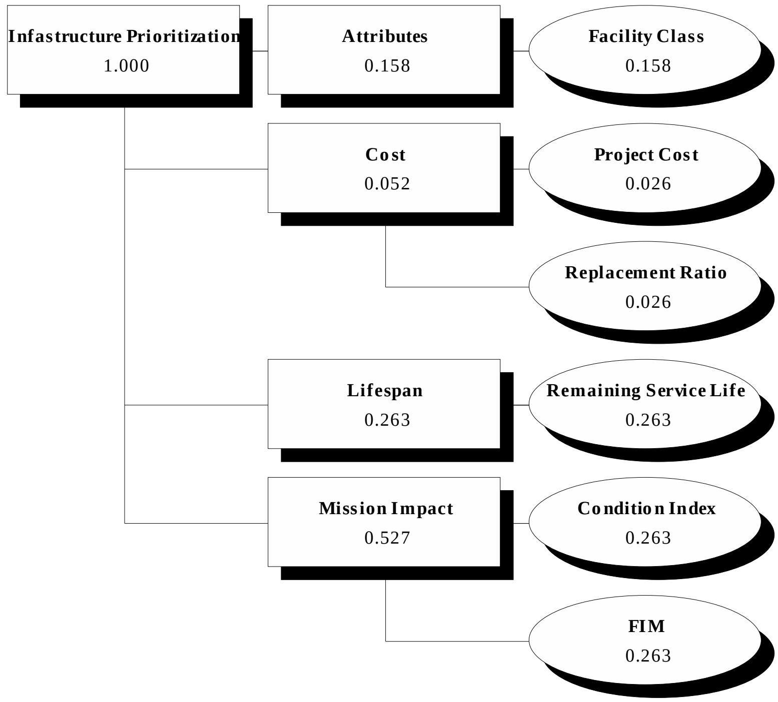


**Figure 11. Global Hierarchy Values for Overall Improvement by Condition**

The third funding strategy (minimizing facility degradation) also had cost as the value of least importance. The remaining values were weighted in proportion to cost as shown in the equations below. The equations were then summed to one to determine their global weights in the hierarchy. The resulting weights are shown in Figure 12 in the value hierarchy.

$w_{(cost)}$ is the least value increment

$$w_{(class)} = 3 * w_{(cost)}$$
$$w_{(condition)} = 10 * w_{(cost)}$$
$$w_{(lifespan)} = 10 * w_{(cost)}$$
$$w_{cost} + w_{lifespan} + w_{condition} + w_{class} = 1$$
$$w_{cost} + 3w_{cost} + 10w_{cost} + 10w_{cost} = 1$$

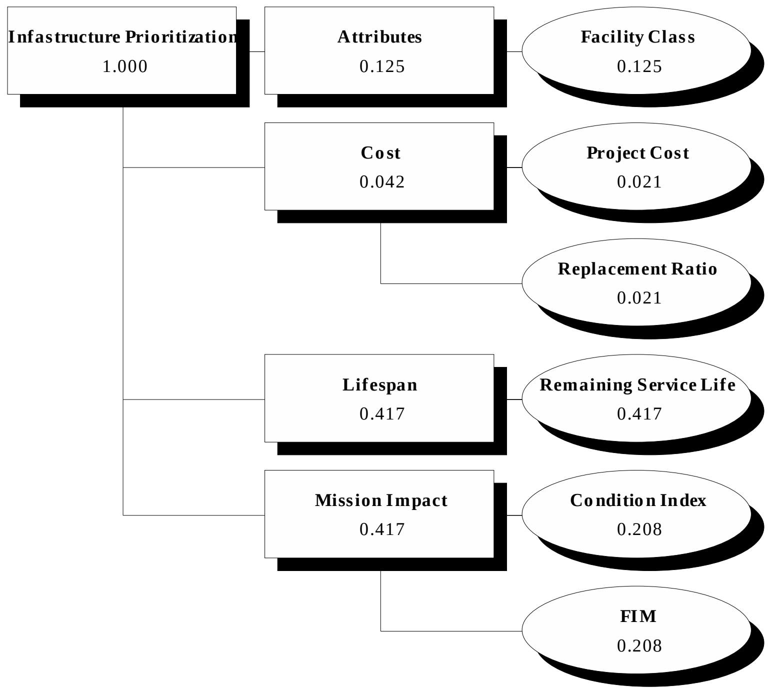


**Figure 12. Global Hierarchy Values for Minimizing Facility Degradation**

### 3.6 Step 6: Alternative Generation

After weighting the hierarchy, the next step in the VFT process is to generate alternatives to be considered. The projects used were generated by Base X for funding from the restoration and modernization account in Fiscal Year 2005. The requirements typically result from user-defined initiatives or inputs from the base civil engineer organization. There is potential for other projects in future fiscal years to be considered in the prioritization process; however, for the purpose of this research, the alternatives were limited to a single fiscal year. Appendix B has the list of all projects considered for evaluation.

### 3.7 Step 7: Scoring

After the alternatives were generated, they were scored according to the single dimension value function developed for each measure in the hierarchy. This presents an unbiased and objective view of the data. However, if the data is difficult to obtain or there are too many measures in a complex model, scoring the alternatives can be difficult and enhance the perceived unreliability of the model by the decision maker.

### 3.8 Summary

This chapter covered Steps 1 through 7 of the Value-Focused Thinking Process. It presented how the value model was created and discussed the development of the evaluation measures, single dimension value functions, and weighting of the value hierarchy. The funding strategies and their application were also discussed. Chapter 4 will discuss the steps 8 and 9 of the VFT process with deterministic and sensitivity analysis of the alternatives.

## IV: Results and Analysis

### 4.1 Overview

This chapter covers Steps 8 and 9 of the Value-Focused Thinking (VFT) process; it also includes additional analyses of three funding strategies. Using the measures identified in Chapter 3, real-world data from Base X was entered into the value model and evaluated using the Logical Decision software. Deterministic and sensitivity analyses were then accomplished with the results. Additional analyses were conducted to determine the benefits of one funding strategy over another. This was accomplished by comparing various measures of effectiveness for each strategy.

### 4.2 Step 8: Deterministic Analysis

In this step of the VFT process, the alternatives are ranked according to their overall contribution (i.e., value) to the fundamental objective. This is accomplished through the additive function, which is the product of the scaling weights established for each of the measures and the resultant value from the single dimension value function determined in Step 7 (Kirkwood, 1997:230). The additive value function is shown in the formula,

$$v(x) = \sum_{i=1}^{n} \lambda_i v_i(x_i) \tag{16}$$

where

$\lambda_i$ = scaling constants or weights

$\upsilon_i(x_i)$ = single dimension value function.

After the scores are determined, the alternatives are typically listed from the best case to worst case, or most preferred to least preferred alternative, respectively. In deterministic analysis using the Logical Decisions software, a colored bar graph or stacked bar represents the proportion of each measure's influence on the alternative's total score. Bar graphs of the deterministic analysis for each funding strategy are provided in Figures 12, 13, and 14, respectively.

**4.2.1 Funding Strategy – Overall Improvement of Facilities by Class.** The results of the first funding strategy, overall improvement of facilities by class, are shown in Figure 13. The first eight projects have a larger emphasis in the area of attributes because these projects have the facility class of operations and training which has a higher utility value. Additionally, the value of cost was also more consistent among all of the alternatives with the exception of one project, *Project 030035 Rpr/Regrade BAK 12/14*. It did not score at all in the cost goal because the project cost value exceeded $1 million.

The projects that had a high lifespan score were the airfield projects. suggesting that these infrastructure systems are approaching the end of their serviceable life and are in need of recapitalization to continue to support the flying mission of Base X. Mission impact was the goal that had the most significant variations due to the scoring of the condition assessment and FIM for each of the alternatives. Most of the condition index values for all the alternatives were moderate. The stratification of alternatives for the mission impact goal is attributed to the FIM whose utility value is increased with the

critical and degraded ratings. The overall scores between the alternatives did not vary significantly which signifies that adjusting the weighting of the values can easily shift the priority of the alternatives.

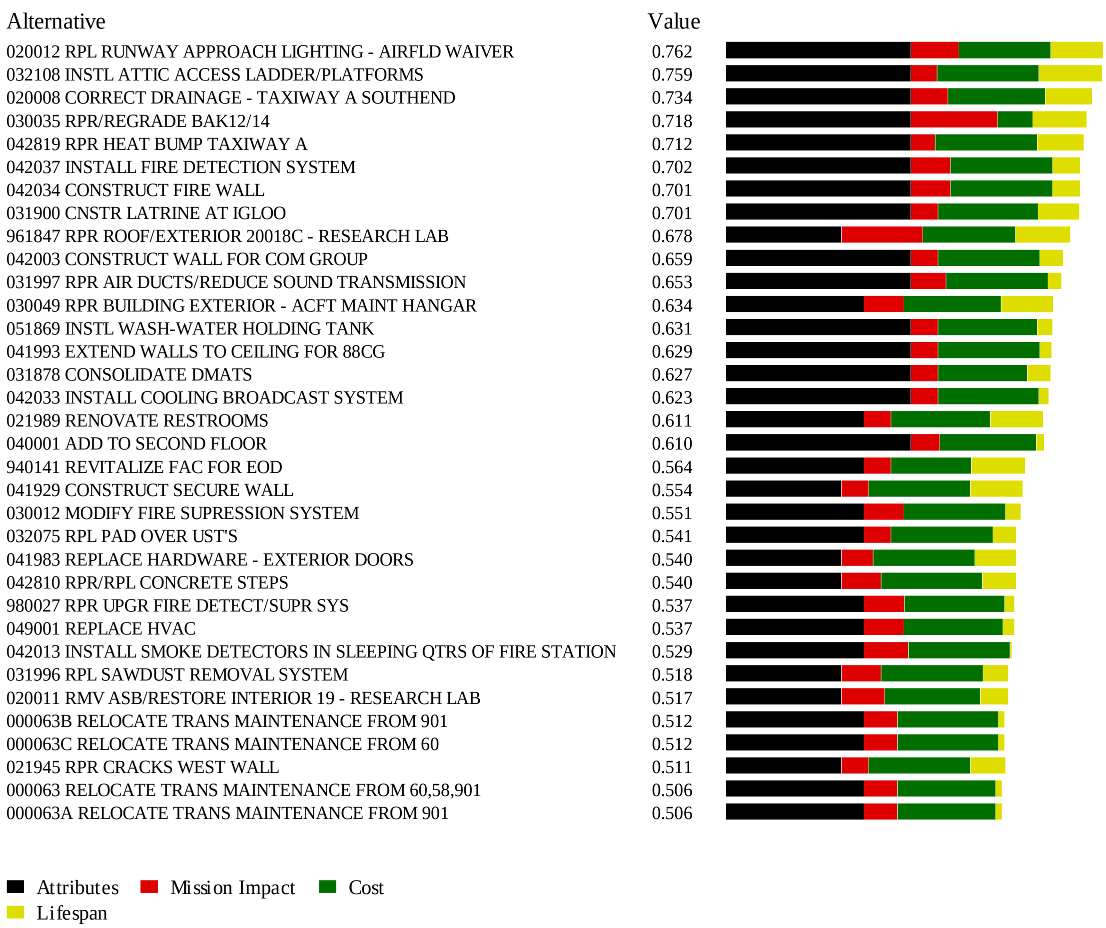


**Figure 13. Deterministic Analysis for Overall Improvement by Facility Class**

**4.2.2 Funding Strategy – Overall Improvement of Facilities by Condition.** Under this funding strategy, cost was the least variant goal of the model. As shown in the

previous funding strategy, *Project 030035  Rpr/Regrade BAK 12/14*, still maintains a low value for cost.  The top alternative, *Project 961847 Rpr Roof/Exterior 20018C –Research Lab*, received a high score for cost.  The remaining projects are closely associated in overall score, thus providing the insight that minimal adjustments of the weighting of the funding strategy may reallocate the priority of projects.  For the top five alternatives, the lifespan value was consistent.  Again, the decision maker can see that the alternatives with the high value of lifespan are airfield projects.  The project, *030010 Reloc 88 LG Weapons Vault from 30256,* scored the least in lifespan due to the number of renovations already accomplished; however, in the area of mission impact, it has a FIM condition rating of critical.

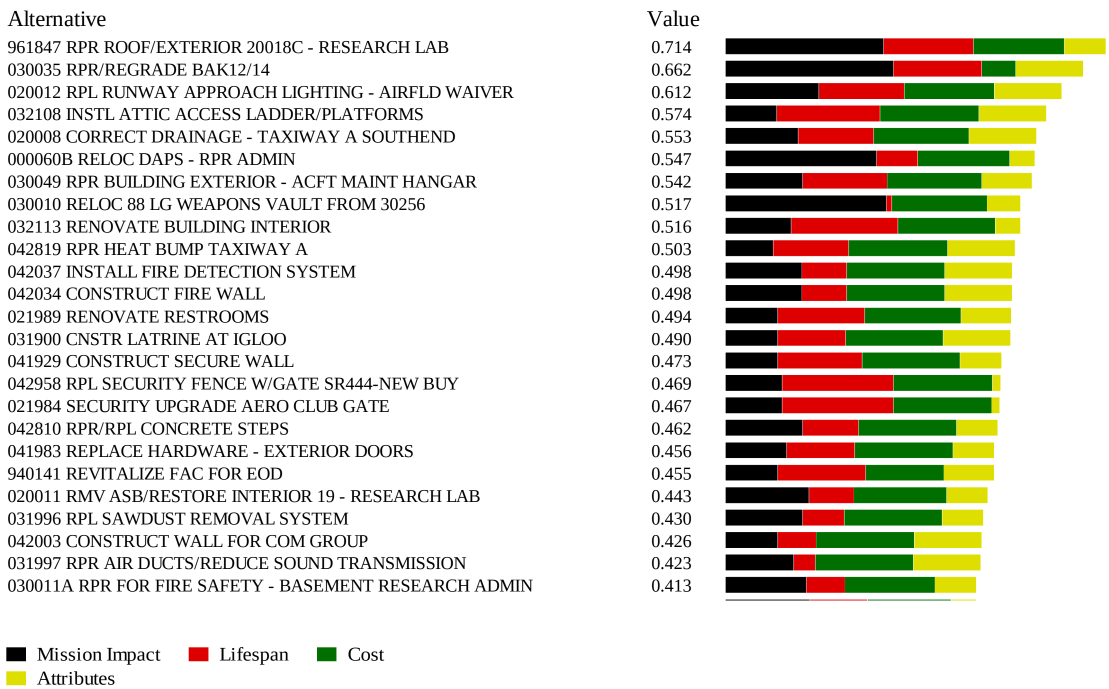


**Figure 14. Deterministic Analysis for Improving Facilities by Condition**

**4.2.3 Funding Strategy – Minimizing Facility Degradation.** The last funding strategy emphasizes lifespan and mission impact. The value of lifespan is relatively consistent for all the alternatives and assumes at least one-third to half the score for each alternative. The next discriminator between the alternatives is mission impact. The top two alternatives have a higher score due to the FIM condition rating of critical.

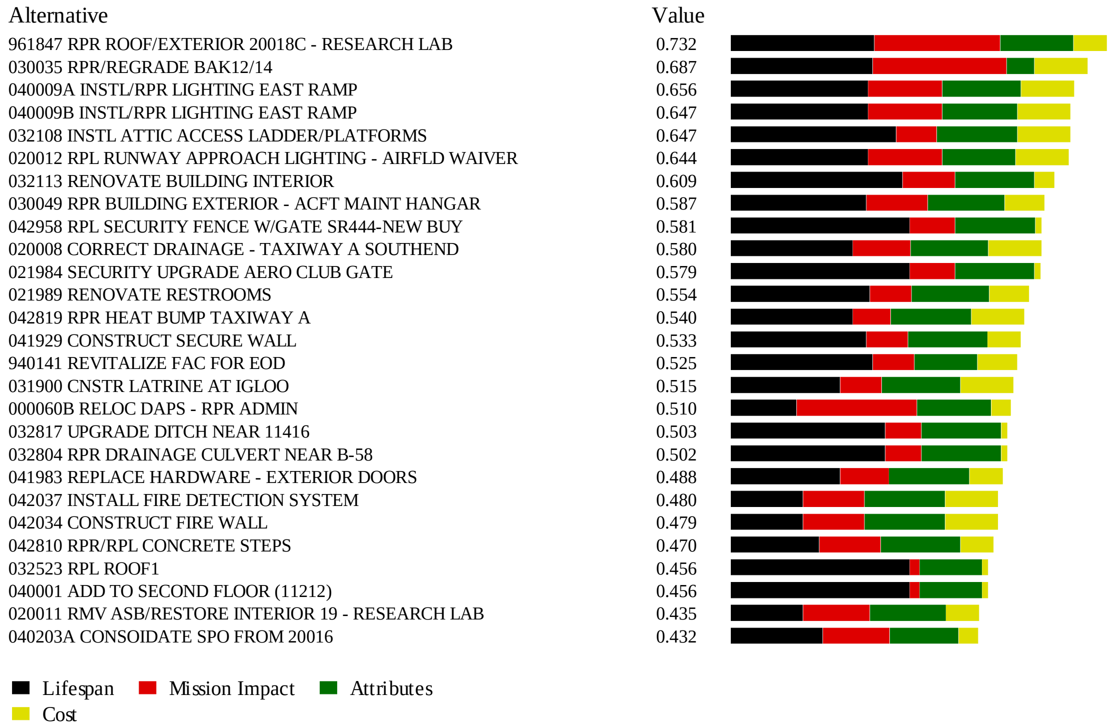


**Figure 15. Deterministic Analysis for Minimizing Facility Degradation**

## 4.3 Step 9: Sensitivity Analysis

This step provides additional insight to the decision maker on how changing the weights of the various goals or measures can impact the ranking of the alternatives. If there is conflict among the various stakeholders about the weight of a particular goal or measure, sensitivity analysis can also show how the changes in the weights can alter the overall decision (Kirkwood, 1997:82). It can also show how much a measure's weight must deviate before it can alter the rankings of alternatives.

The use of the three funding strategies in effect provides the application of sensitivity analysis to the value model. Each funding strategy has a different weighting

scheme and as a result illustrates to the decision maker the effect of the weights applied. For the sensitivity analysis, only 15 projects were evaluated to illustrate the concept of evaluating how the adjustment of the values' weight can alter the priority of the projects.

**4.3.1 Sensitivity Analysis Based on Attributes.** The sensitivity analysis of the attributes value is shown in Figure 16. It illustrates that when the global weight is adjusted from 47.1 percent in the positive direction, it is insensitive to change for the top 12 alternatives. However, the attributes value objective is most sensitive to change in the negative direction. The project that ranks worst in the attributes is, *Project 961847 Rpr Roof/Exterior 20018C – Research Lab,* because it is a research, development, training and education facility. All other projects, due to their facility class of operations and training perform, well in this measure. Furthermore, the common groupings and slope of projects are due to like facility classes. Therefore, this analysis can provide insight to the decision maker about which facility classes he would like to focus on to correct the C-Ratings for that facility class.

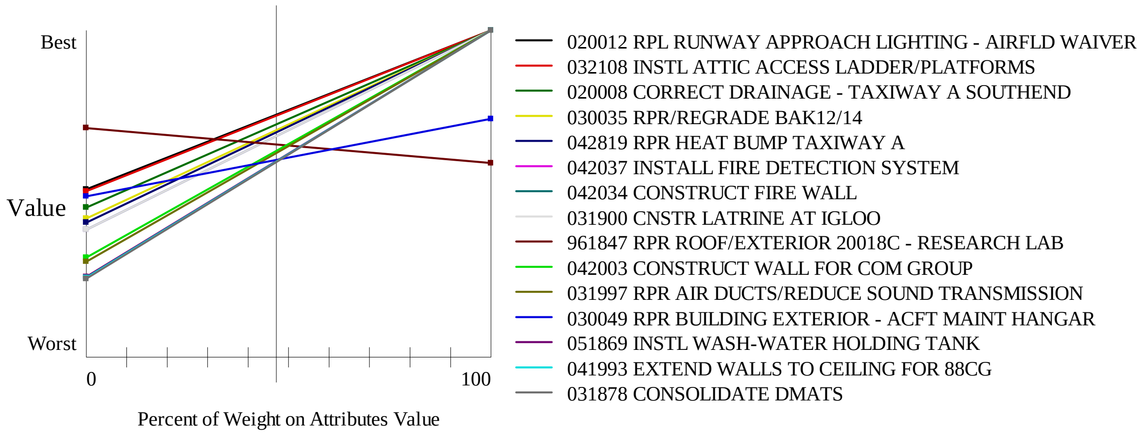


**Figure 16. Sensitivity Analysis for Attributes**

**4.3.2 Sensitivity Analysis Based on Cost.** This sensitivity analysis shows that cost is insensitive to change in the positive direction from 10 to 100 percent. However, in the negative direction, it is very sensitive to change. *Project 030035 Repair/Regrade BAK 12/14*, performs the worst in this value objective. In addition, if cost is a significant issue, this project might be one that needs to be completed soon because cost amplification may occur if it is delayed.

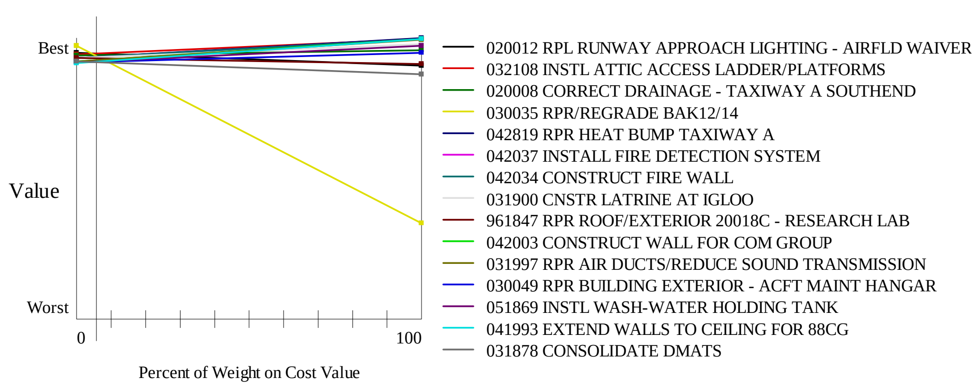


**Figure 17. Sensitivity Analysis for Cost**

**4.3.4 Sensitivity Analysis Based on Mission Impact.** Mission impact is sensitive in both the positive or negative direction. If this value objective was maximized, the majority of the projects would not perform well due to their negative slope because these alternatives have a condition rating of degraded or essential and a condition index of 5 or greater. However, the two projects that would perform well are *Projects 030035 Repair/Regrade BAK 12/14* and *Project 961847 Rpr Roof/Exterior 20018C – Research Lab* due to their critical FIM rating and their moderate values under the condition index measure.

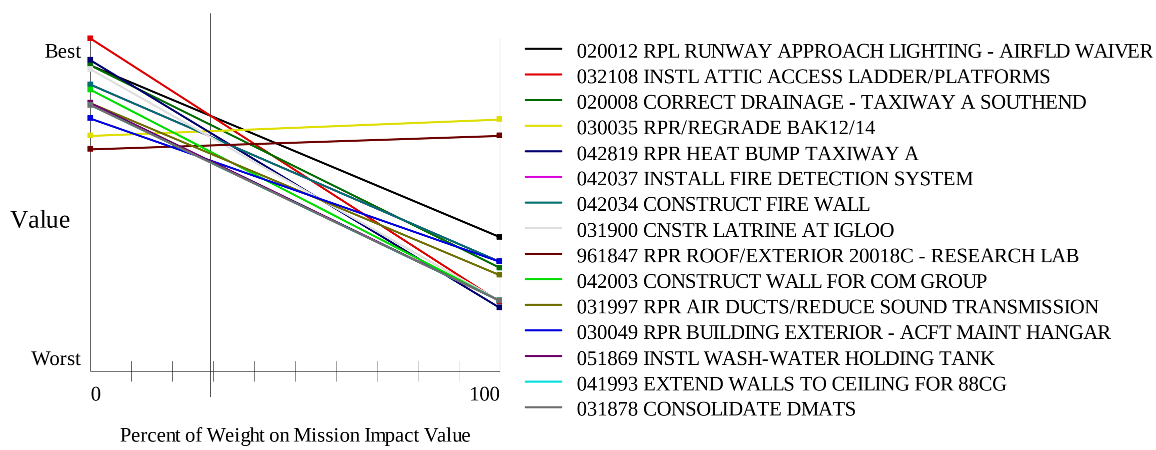


**Figure 18. Sensitivity Analysis for Mission Impact**

**4.3.5 Sensitivity Analysis Based on Lifespan.** The sensitivity analysis for the life span value objective illustrates that it is also very sensitive to change. Weight increases by 10 percent in the negative to 10 percent in the positive direction can adjust the ranking of the

alternatives.  If the weight of lifespan was at its maximum value of 100 percent, *Project 032108 Instl Attic Access Ladder/Platforms*, ranks the highest, illustrating that this alternative has the worst value in remaining service life.  Projects not performing well in this measure have a remaining service life of 50 years or better.  Additional sensitivity graphs for each measure under are shown in Appendix C.

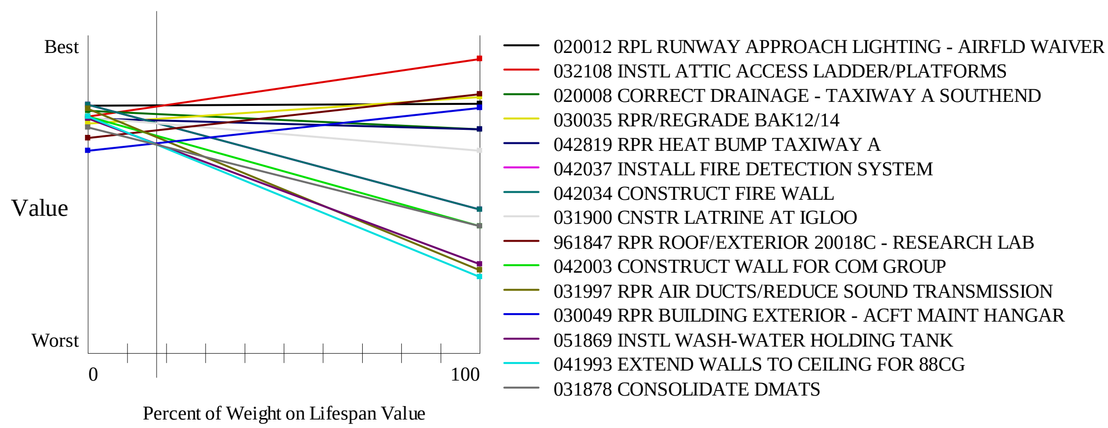


**Figure 19.  Sensitivity Analysis for Lifespan**

## 4.4  Measures of Effectiveness

Since the decision makers and the infrastructure priorities may deviate from installation to installation, showing how the projects rank and compare within the various funding strategies can also provide additional insight to the decision maker as to the better projects to fund.  The measures of effectiveness developed for this research are:

the average ranking of alternatives for multiple funding strategies, improving the C-ratings for each facility class by advancing the cost to C-2, the impact to condition assessment for each facility class, and influence of each funding strategy on extending the service life of facilities.

**4.4.1 Ranking of Alternatives.** Common projects that rank high with the various funding strategies can provide additional justification for the funding of these particular requirements. Additionally, if each funding strategy is considered as part of an entire funding strategy, a weighted average can be assessed for each of the funding strategies:

$$\alpha_1 w_1 + \alpha_2 w_2 + \alpha_2 w_2 = 1 \tag{16}$$

where,

$\alpha_i$ = weight assigned to a particular funding strategy

$w_i$ = rank order of the project resulting for each funding strategy

For example, suppose a funding limit of $10M was established to compare the projects prioritized under the various funding strategies. If the funding strategies were assigned an equal weight, the results can be seen in Table 1. After applying equal weighting to all funding strategies, the average ranking for each the projects was calculated and shown

below.  There are eleven projects that had an average ranking above ten for all funding strategies highlighted in the table.

**Table 1.  Ranking of Projects**

| Project Number | Project Title | FUNDING STRATEGIES | | | Average Ranking |
|---|---|---|---|---|---|
| | | Attributes | Mission Impact | Minimize Degradation | |
| ZHTV030035 | RPR/REGRADE BAK12/14 - AIRFIELD WAIVER * | 4 | 2 | 2 | 3 |
| ZHTV020012 | RPL RUNWAY APPROACH LIGHTING – AIRFLD WAIVER | 1 | 5 | 6 | 4 |
| ZHTV020008 | CORRECT DRAINAGE - TAXIWAY A SOUTHEND | 3 | 7 | 10 | 7 |
| ZHTV031900 | CNSTR LATRINE AT IGLOO | 8 | 16 | 16 | 13 |
| ZHTV021989 | RENOVATE RESTROOMS | 17 | 15 | 12 | 15 |
| ZHTV032108 | INSTL ATTIC ACCESS LADDER/PLATFORMS | 2 | 6 | 5 | 4 |
| ZHTV042819 | RPR HEAT BUMP TAXIWAY A - NEW BUY | 5 | 12 | 13 | 10 |
| ZHTV961847 | RPR ROOF/EXTERIOR 20018C - RESEARCH LAB | 9 | 1 | 1 | 4 |
| ZHTV042037 | INSTALL FIRE DETECTION SYSTEM | 6 | 13 | 21 | 13 |
| ZHTV042034 | CONSTRUCT FIRE WALL | 7 | 14 | 22 | 14 |
| ZHTV030049 | RPR BUILDING EXTERIOR - ACFT MAINT HANGAR | 12 | 9 | 8 | 10 |
| ZHTV940141 | REVITALIZE FAC FOR EOD | 19 | 22 | 15 | 19 |
| ZHTV041929 | CONSTRUCT SECURE WALL | 20 | 17 | 14 | 17 |

### 4.4.2  Reduce the IRR Cost to C2

As stated in Chapter 2, the C-Ratings are evaluated for each facility class as part of the installation and facilities segment of the Defense Readiness Reporting System (Installations Policy Board, 2001:19).  For this measure of effectiveness, the goal might be to correct facility deficiencies to attain at least a C-2 rating for those facility classes

currently rated at C-3 and C-4. To improve the various C-ratings for each facility class, Base X has identified the required projects to reach C-2 status using Table 2.

**Table 2. C-Ratings for Base X**

| Facility Class | Calculated C-Rating | Commander's C-Rating |
|---|---|---|
| Operations/Training | C-3 | C-3 |
| Mobility | C-1 | C-1 |
| Maintenance/Production | C-3 | C-3 |
| RDTE | C-3 | C-3 |
| Supply | C-2 | C-2 |
| Medical | C-1 | C-1 |
| Administrative | C-4 | C-3 |
| Utility/Grounds Improvement | C-2 | C-2 |
| Community Support/ Military Family Housing | C-2 | C-2 |
| Dormitories | C-1 | C-2 |
| Military Family Housing | C-3 | C-3 |
| Community Support | C-2 | C-2 |

Assuming the same $10 million funding limit for all funding strategies, Table 3 shows which projects were used for each corresponding funding strategy. As shown in the table, the funding strategies of facility class and facility condition have the most C-2 projects identified for prioritization. This method can illustrate how effective the funding strategies are in discriminating these necessary projects for elevation and funding prioritization.

**Table 3. Projects Advancing the C-Ratings to C-2**

| Project Number | Project Title | FUNDING STRATEGIES | | |
|---|---|---|---|---|
| | | Attributes | Mission Impact | Minimize Degradation |
| ZHTV032113 | RENOVATE BUILDING INTERIOR | | X | X |
| ZHTV040203A | CONSOLIDATE SPO FROM 20016 | | | X |
| ZHTV000060B | RELOC DAPS - RPR ADMIN | | X | X |
| ZHTV032523 | RPL ROOF | | | X |
| ZHTV030012 | MODIFY FIRE SUPRESSION SYSTEM | X | | |
| ZHTV030049 | RPR BUILDING EXTERIOR - ACFT MAINT HANGA | X | | |
| ZHTV042013 | INSTALL SMOKE DETECTORS IN SLEEPING QTRS | X | | |
| ZHTV032075 | RPL PAD OVER UST'S | X | | |
| ZHTV940141 | REVITALIZE FAC FOR EOD | X | X | X |
| ZHTV020008 | CORRECT DRAINAGE - TAXIWAY A SOUTHEND | X | X | |
| ZHTV030035 | RPR/REGRADE BAK12/14 - AIRFIELD WAIVER | X | X | X |
| ZHTV020012 | RPL RUNWAY APPROACH LIGHTING - AIRFLD WA | X | X | X |
| ZHTV049001 | REPLACE HVAC (12140) | X | | |
| ZHTV031997 | RPR AIR DUCTS/REDUCE SOUND TRANSMISSION | X | | |
| ZHTV031996 | RPL SAWDUST REMOVAL SYSTEM | X | X | |
| ZHTV030011A | RPR FOR FIRE SAFETY - BASEMENT RESEARCH | X | X | |
| ZHTV961847 | RPR ROOF/EXTERIOR 20018C - RESEARCH LAB | X | X | |
| ZHTV020011 | RMV ASB/RESTORE INTERIOR 18 - RESEARCH L | X | X | X |
| ZHTV042810 | RPR/RPL CONCRETE STEPS | X | X | X |
| | **# OF PROJECTS:** | **15** | **11** | **13** |

**4.4.3 Impact to the Condition Assessment.** The purpose of this measure of effectiveness is to evaluate the impact of each funding strategy on the Facility Investment Metric (FIM) condition rating for each facility class. The number of the FIM ratings occurring for each facility class is shown in Table 4 below. Prioritizing projects through the funding strategy of overall improvement of facilities by class has the most potential to provide greater improvement to the facility classes of operations and training, RDT&E, maintenance and production and supply.

## Table 4. Funding Strategy Impact on Facility Class Condition

| Facility Class Category | FIM Rating | Funding Strategy | | |
|---|---|---|---|---|
| | | Facility Class | Mission Impact | Minimize Facility Degradation |
| Operations/Training | CRITICAL | 1 | 1 | 1 |
| | DEGRADED | 6 | 5 | 4 |
| | ESSENTIAL | 6 | 2 | 1 |
| Mobility | CRITICAL | 0 | 0 | 0 |
| | DEGRADED | 0 | 0 | 0 |
| | ESSENTIAL | 0 | 0 | 0 |
| RDT&E | CRITICAL | 1 | 1 | 1 |
| | DEGRADED | 3 | 4 | 2 |
| | ESSENTIAL | 3 | 2 | 2 |
| 0 | CRITICAL | 0 | 0 | |
| 3 | DEGRADED | 6 | 3 | |
| 4 | ESSENTIAL | 8 | 4 | |
| 0 | CRITICAL | 0 | 1 | |
| 0 | DEGRADED | 0 | 0 | |
| 0 | ESSENTIAL | 0 | 0 | |
| 1 | CRITICAL | 0 | 0 | |
| 1 | DEGRADED | 0 | 0 | |
| 2 | ESSENTIAL | 1 | 1 | |
| 0 | CRITICAL | 0 | 0 | |
| 0 | DEGRADED | 0 | 0 | |
| 0 | ESSENTIAL | 0 | 0 | |
| 0 | CRITICAL | 0 | 0 | |
| 0 | DEGRADED | 0 | 0 | |
| 4 | ESSENTIAL | 0 | 0 | |

**4.4.4 Service Life .** The purpose of assessing the service life or age of the installation's facilities is to estimate how much the service life can be extended with the various projects listed under each funding strategy. Using Cushing's formula for adjusted age as referenced in Chapter 2, the component weight or renovation fraction can illustrate how much impact a project can have towards extending the service life of a facility.

As shown in Appendix D, the first funding strategy (overall improvement by facility class) and the third funding strategy (minimizing facility degradation) have the highest potential for extending the service life of the infrastructure. The decision maker can select the funding strategy based on that value or also consider the renovation fraction which is how much a specific project can further extend the service life of a particular facility or infrastructure system. The projects with higher renovation fractions have the potential to increase the service life more than those projects with a lower renovation fraction. The decision maker can select either metric on which to base a decision.

## 4.5 Summary

The VFT model can provide additional insight to the decision maker regarding the values considered to have the most importance (i.e., value) to the decision being made. Furthermore, using measures of effectiveness to compare various funding strategies provides more detailed insight regarding the benefits and drawbacks of the funding strategies. Based on the different measures of effectiveness, the funding strategy that consistently provided the most impact was the one based on an overall improvement of facilities by class. It demonstrated the best improvement for the number of C-2 projects

included in the prioritized list and the greatest extension for service life. Furthermore, evaluating the funding strategies by looking at the ranking of projects and the renovation fraction helped identify common projects that were consistently ranked high and should be funded as well as the converse of identifying projects that were ranked at the bottom and should be eliminated. Readily identifying projects based on their ranking can aid the decision maker and key stakeholders so they can spend their time more effectively on decisions impacting the middle of the pack projects.

# V. Conclusion and Recommendations

## 5.1 Overview

This chapter provides a review of this research effort while answering the questions presented in Chapter 1. It discusses the development of the value model as a tool for the Air Force to utilize for infrastructure prioritization. Additionally, an evaluation of the model's strengths and limitations are presented as well as the recommendations for future research in this area.

## 5.2 Review of Research Questions

Although there are various methods available to prioritize and identify infrastructure and facility projects for funding, the VFT method was identified and determined to be the preferred method under decision analysis because of its ability to be objective, defendable, and repeatable. The value model created was based on the direction of Air Force Instruction, budget models and prioritization methods, as well as input from the sponsor, the Air Force Material Command Chief of Infrastructure and Facilities, who was also the proxy decision maker in the decision process. The values and measures used in the model with the input of the proxy decision maker validate the gold standard of the model. The development of the decision analysis tool helped answer the research questions outlined in Chapter 1.

**1. What does the Air Force value in identifying which restoration and modernization projects to fund?**

Creating the value hierarchy defined in Step 2 of the value-focused thinking process was used in identifying the factors. The factors were generated from Air Force Instruction and budget models and prioritization methods. In discussions with the proxy decision maker, the measures implemented in the model were the significant factors that were considered important to the decision maker in discriminating projects for funding.

**2. What is the impact to the overall lifespan and condition of infrastructure systems and facilities under the three various funding strategies?**

The measures of effectiveness, which included improving the recapitalization rate; reducing the C-Ratings to C-2, the change in service life, and change in condition assessment; were used to evaluate how the lifespan and condition of infrastructure systems and facilities under the various funding strategies were impacted. The funding strategy that had the most impact was determined to be one based on an overall improvement of facilities by class.

**3. What are the advantages and disadvantages to the new infrastructure prioritization tool versus that of the current Air Force method?**

The advantages of the new infrastructure prioritization tool versus that of the current Air Force method are that: it allows the decision maker to evaluate a prioritized list of projects without the demonstrative appeals from organizations attempting to elevate their projects for prioritization, it provides an objective list for the decision maker based on his or her requirements through the various funding strategies, and it enables the decision maker to evaluate the potential impact of each funding strategy on the condition and lifecycle of the facilities and infrastructure systems. The disadvantage of the new

infrastructure prioritization tool is that it is a new methodology that may not readily be accepted or applied through the Air Force. In order for this method to be adopted, a long-term strategy for implementation and approval by senior leaders needs to take place.

### 5.3 Model Strengths

The value model provides an objective and defendable method to prioritize infrastructure projects for a decision maker's approval. The model's objectivity stems from the value hierarchy developed and weighted prior to the evaluation of alternatives. The alternatives that are ranked are a reflection of the funding strategy(s) desired by the decision maker. Since funding strategies are utilized rather than having an individual decision maker determine the weights of the value hierarchy, the flexibility of the model is enhanced because it reduces bias. Additionally, the use of funding strategies allows flexibility of the model to be implemented for any decision maker at any level and installation.

The value model is also straightforward and simplistic, which enables it to be easily understood and defendable. The majority of the measures used in the model are captured in the Automated Civil Engineer System (ACES), so the data is not difficult to acquire. Given that the data is readily available, it presents a highly usable method for civil engineers to present to decision makers as an objective, defendable, flexible method for recommending projects for infrastructure prioritization. If the model were to be used by other services or organizations, the measures included could easily be adjusted to meet the availability of their data and infrastructure program requirements.

## 5.4 Model Limitations

The primary limitation for this value model was the calculation of the adjusted age for each infrastructure system. This value required extensive review of historical project data for each infrastructure system considered for prioritization. Moreover, the adjusted age calculation used is an estimate since the service life cannot be accurately measured based on the data available in ACES without the additional use of life-cycle analysis software. Utilizing a more practical method for calculating remaining service life may also increase the usability of the model. Additionally, the model would be more practical for base civil engineers if the value-focused thinking analysis software could be directly integrated into ACES. Although the Logical Decision software program can be converted to an Excel spreadsheet, the fact that a separate tool or program for this analysis is required reduces the ability for this model's implementation in the field.

## 5.5 Conclusions

The purpose of this research was to develop a decision management tool to objectively evaluate which infrastructure systems and facility projects to prioritize for funding and recommend to the decision maker for approval. The VFT process fulfilled this objective through the creation of a value model that included funding strategies and metrics to evaluate the effectiveness of those funding strategies. It is a value model that will enable the decision maker significant insight into the selection of prioritized restoration and modernization projects for funding.

### 5.6 Recommendation for Future Work

Future research can explore a more practical method toward evaluating the remaining service life of facilities or infrastructure systems. A single fiscal year was assessed in the value model. Additional projects of future fiscal years can be included in the value model to determine if those projects should be advanced ahead of their designated fiscal year. Finally, integration of the value model with the ACES database can be a powerful tool for the decision maker or key stakeholders toward recommending and providing objective justification for project prioritization and funding.

# Appendix A. Base X Restoration and Modernization Projects

## Table 5. Base X Restoration and Modernization Projects

| Project Number | Project Title | Programmed Amount | FIM | FDSC | RAC |
|---|---|---|---|---|---|
| | | | | | |
| 000068 | RMV TEMPORARY WALLS | $11,200 | ESS | | |
| 031930 | RELOC ME FROM 30169 | $119,600 | DEG | | |
| 032075 | CNSTR WALL AROUND GENERATOR | $16,000 | ESS | | |
| 032108 | RPL PAD OVER UST'S | $25,000 | ESS | | |
| 032523 | INSTL ATTIC ACCESS LADDER/PLATFORMS | $11,600 | ESS | | |
| 032804 | RPL ROOF | $180,000 | ESS | | |
| 032840 | RPR DRAINAGE CULVERT NEAR B-58 | $118,600 | ESS | | |
| 040034A | SECURE VACANT SPACE | $5,000 | ESS | | |
| 041867 | RPL/RPR WATER MAIN - KHC OPT 1 | $91,000 | ESS | | |
| 041997 | INSTL SPRINKLERS HALLWAY | $5,500 | DEG | 3 | |
| 042006 | RPR LATRINES FOR 47ALF | $57,000 | ESS | | |
| 042011 | RECONFIGURE ROOMS FOR 88ABW | $6,000 | ESS | | |
| 042026 | RPR DOOR RELOCATE LADDER AFRL | $10,600 | DEG | | 3 |
| 042028 | RPR DRAIN LINE IN BREAK ROOM ASC/YC | $22,200 | ESS | | |
| 042054 | RPL 2" GAS LINE - FISHER HOUSE | $5,000 | ESS | | |
| 042069 | INSTL FIRE SUPRESSION SYS LOBBY | $14,000 | DEG | 3 | |
| 042810 | RPR/RPL CONCRETE STEPS | $50,250 | DEG | | 3 |
| 042819 | RPR HEAT BUMP TAXIWAY A -NEW BUY | $1,700 | ESS | | |
| 042958 | RPL SECURITY FENCE W/GATE SR444-NEW BUY | $9,000 | ESS | | |
| 051876 | RPL WINDOW GLASS | $27,300 | ESS | | |
| 052804 | RPR MANHOLES NEAR 20026 | $19,000 | ESS | | |
| 051869 | INSTL WASH-WATER HOLDING TANK | $22,700 | ESS | | |
| 041884 | INSTL ALARMS VAULTS 1.3 & 1.4 | $14,000 | ESS | 3 | |
| 041962 | RPL LOBBY FINISHES | $15,400 | ESS | | |
| 032113 | RENOVATE BUILDING INTERIOR | $130,600 | ESS | | |
| 041944 | UPGRADE SECURITY INC ACCESS CONTROL | $67,000 | ESS | | |
| 0030046E | COMPUTER SPACE RECONFIGURATION | $55,506 | ESS | | |
| 032031 | RECONFIGURE POWER AT DODGE GYM POOL | $16,900 | ESS | | |
| 051870 | REMODEL VIDEO STUDIO W156 | $75,900 | ESS | | |
| 042068 | RECONFIGURE RM 227A | $12,500 | ESS | | |
| 040001 | ADD TO SECOND FLOOR (11212) | $645,000 | ESS | | |
| 021989 | RENOVATE RESTROOMS | $100,000 | ESS | | |
| 961847 | RPR ROOF/EXTERIOR 20018C - RESEARCH LAB | $970,000 | CRI | | |
| 030035 | RPR/REGRADE BAK12/14 - AIRFIELD WAIVER * | $1,052,000 | CRI | | 2 |
| 020011 | RMV ASB/RESTORE INTERIOR 18 – RESEARCH LAB | $740,000 | DEG | | 3 |
| 040022 | RPR/UPGRADE FIRE ALARM SYS - NAIC HQ VAULT/ADMIN | $500,000 | DEG | 2 | |
| 020012 | RPL RUNWAY APPROACH LIGHTING - AIRFLD WAIVER | $1,350,000 | DEG | | 3 |
| 030049 | RPR BUILDING EXTERIOR - ACFT MAINT HANGAR | $465,000 | DEG | | 2 |
| 030011A | RPR FOR FIRE SAFETY - BASEMENT RESEARCH ADMIN * | $1,200,000 | DEG | 3 | |
| 000060B | RELOC DAPS - RPR ADMIN | $878,000 | CRI | | |
| 040003 | CNS ADDITIONAL BAYS & STORAGE – FD | $660,000 | DEG | | |
| 980052 | RPR FIRE SAFETY/PLUMBING – VOQ | $1,675,000 | DEG | 3 | |
| 030023 | RPL WATER SYS BTW 10TH & 5TH ST * | $2,500,000 | DEG | 3 | |
| 030010 | RELOC 88 LG WEAPONS VAULT FROM 30256 | $307,500 | CRI | | |
| 030011B | RPR FOR FIRE SAFETY 1ST & 2ND FLRS - RESEARCH ADMIN | $2,000,000 | DEG | 3 | |
| 940166A | RPR FIRST FLOOR FIRE SUPP/HVAC - PH II 88ABW HQ | $1,500,000 | DEG | 3 | |

| Project Number | Project Title | Programmed Amount | FIM | FDSC | RAC |
|---|---|---|---|---|---|
| | | | | | |
| 031878 | CONSOLIDATE DMATS | $1,000,000 | ESS | | |
| 040203A | CONSOLIDATE SPO FROM 20016 | $2,100,000 | DEG | | |
| 042845 | TRUCK INSPECTION LOT | $150,000 | ESS | | |
| 041871 | REPAIR CRACKS IN CEILING | $480,000 | ESS | | |
| 030002 | INSTL LINE/BOOSTER PUMP - WATER TWR W.R. | $490,100 | ESS | | |
| 940141 | REVITALIZE FAC FOR EOD | $750,000 | ESS | | |
| 021984 | SECURITY UPGRADE AERO CLUB GATE | $101,000 | ESS | | |
| 032011 | UPGR RRMS CHAPEL 2 (YOFAM) | $171,300 | ESS | | |
| 040025 | REROUTE ASH PIPING | $150,000 | ESS | | 4 |
| 030021 | REPLACE BACK-UP WATER SYS AREA B | $640,000 | ESS | | |
| 022093 | REPAIR HANGAR DOORS | $120,000 | ESS | | |
| 000063 | RELOCATE TRANS MAINTENANCE FROM 60,58,901 | $375,000 | ESS | | |
| 000063A | RELOC TRANS MAINT FROM 901 | $375,000 | ESS | | |
| 000063B | RELOC TRANS MAINT FROM 901 | $125,000 | ESS | | |
| 000063C | RELOCATE TRANS MAINT FROM 60 | $125,000 | ESS | | |
| 031869 | RPR HVAC SYSTEM | $198,000 | ESS | | |
| 040413 | REPLACE CIRCUITS BASWIDE | $333,250 | ESS | | |
| 042013 | INSTALL SMOKE DETECTORS IN SLEEPING QTRS OF FIRE STATION | $12,800 | DEG | 3 | |
| 022065 | EXTEND FIRE DETECTION TO SECOND AND THIRD FLOORS | $18,000 | DEG | 3 | |
| 042037 | INSTALL FIRE DETECTION SYSTEM | $19,200 | DEG | 3 | |
| 042034 | CONSTRUCT FIRE WALL | $22,000 | DEG | 3 | |
| 031996 | RPL SAWDUST REMOVAL SYSTEM | $30,000 | DEG | | |
| 031877 | INSTALL STANDPIPE EXTENTION | $30,000 | DEG | 3 | |
| 030012 | MODIFY FIRE SUPRESSION SYSTEM | $33,000 | DEG | 3 | |
| 031997 | RPR AIR DUCTS/REDUCE SOUND TRANSMISSION | $40,000 | DEG | | |
| 032046 | EXTEND FIRE PROTECTION SYS A/F | $50,000 | DEG | 3 | |
| 042058 | EXTEND SPRINKLER SYSTEM | $70,400 | DEG | 3 | |
| 040004 | FIRE PROTECTION | $71,000 | DEG | 3 | |
| 050007 | REPLACE BOILERS | $125,000 | DEG | | |
| 220031 | RECONFIGURE FOR DET 1 PHASE 2 | $131,000 | DEG | | |
| 980027 | RPR UPGR FIRE DETECT/SUPR SYS | $150,000 | DEG | 3 | |
| 049001 | REPLACE HVAC (12140) | $188,600 | DEG | | |
| 970757 | UPGR TRAIN CENTER HVAC* | $210,000 | DEG | | |
| 960631A1 | MODERN FIRE SAFETY/ELEC POWER DISTR - PH 1 | $230,000 | DEG | 3 | |
| 020008 | CORRECT DRAINAGE - TAXIWAY A SOUTHEND | $414,000 | DEG | | |
| 100021 | INSTL COOLING USAF MUSEUM ANNEX | $670,000 | DEG | | |
| 0400401 | REPAIR AFMC HQ FACILITY 10262 | $9,831,300 | DEG | 3 | |

## Appendix B.  Single Dimension Value Functions

The following single dimension value functions were created with the input of the proxy decision maker and through the use of Logical Decisions software.  The graphs represent the value of each measure to the proxy decision maker.  The flexibility of this value model can be shown through the value function.  Figure 20 shows the SDVF for Replacement Ratio.  The proxy decision maker places more value on lower replacement ratios than higher values.

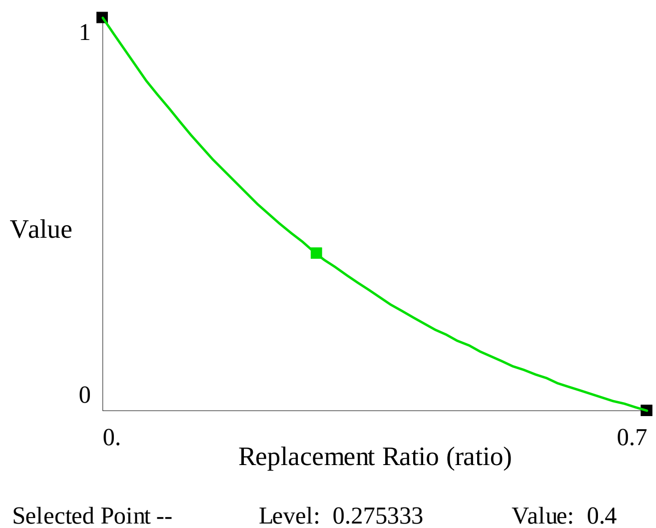


**Figure 20.  Monotonically Decreasing Exponential SDVF for Replacement Ratio**

Figure 21 shows the SDVF for remaining service life.  For this SDVF, the proxy decision maker also prefers low values of remaining service life.  A selected point on the graph shows that 25 has a value of .75

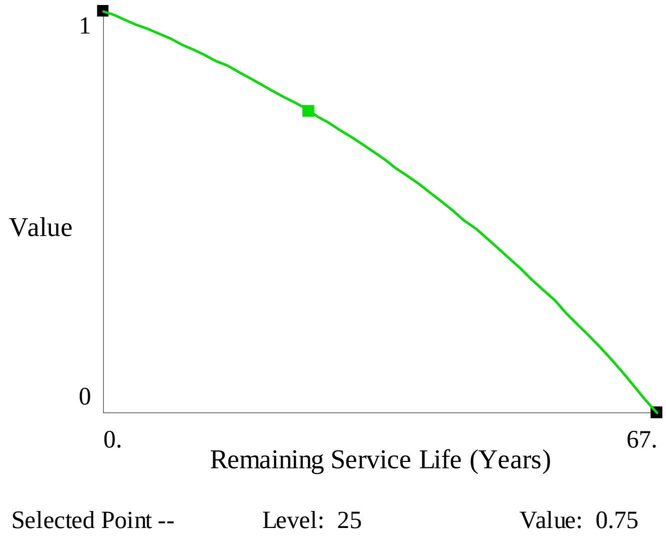


**Figure 21. Monotonically Decreasing Exponential SDVF for Remaining Service Life**

The condition index SDVF shown in Figure 22 is a linear function that decreases proportionately. The most preferred value is alternatives with lower values for the condition index. Lower values indicate a high state of repair is required.

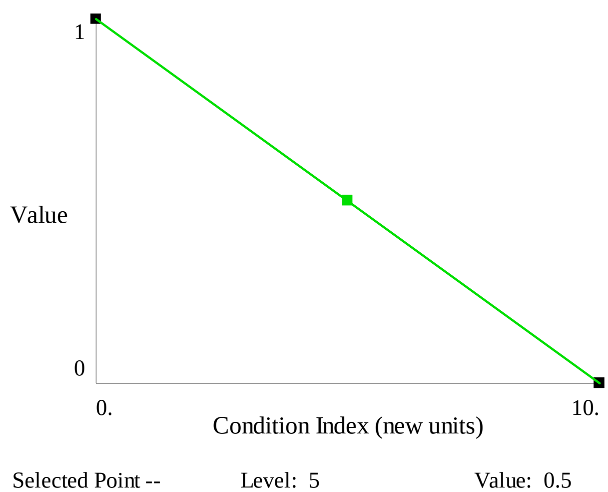


**Figure 22. Monotonically Decreasing Linear SDVF for Condition Index**

Figure 23 illustrates the Facility Investment Metric (FIM) SDVF. It is a categorical function. The proxy decision maker placed more emphasis on the values for "critical" and "degraded" projects than on the "essential" category. The value applied also parallels that of Air Force publications on prioritizing projects based on mission impact.


**Figure 23. Categorical SDVF for FIM**

## Appendix C.  Sensitivity Analysis

This appendix illustrates the sensitivity graphs of the six measures used for each of the funding strategies.  Depending on the weights allocated to the measures and their potential increase or decrease in value, the ranking of alternatives could vary.  As the weight of a particular measure increases or decreases, the corresponding weights of the other measures will increase or decrease proportionately.  These changes can impact the final results of the prioritization of infrastructure projects.

### Funding Strategy 1:  Overall Improvement by Facility Class

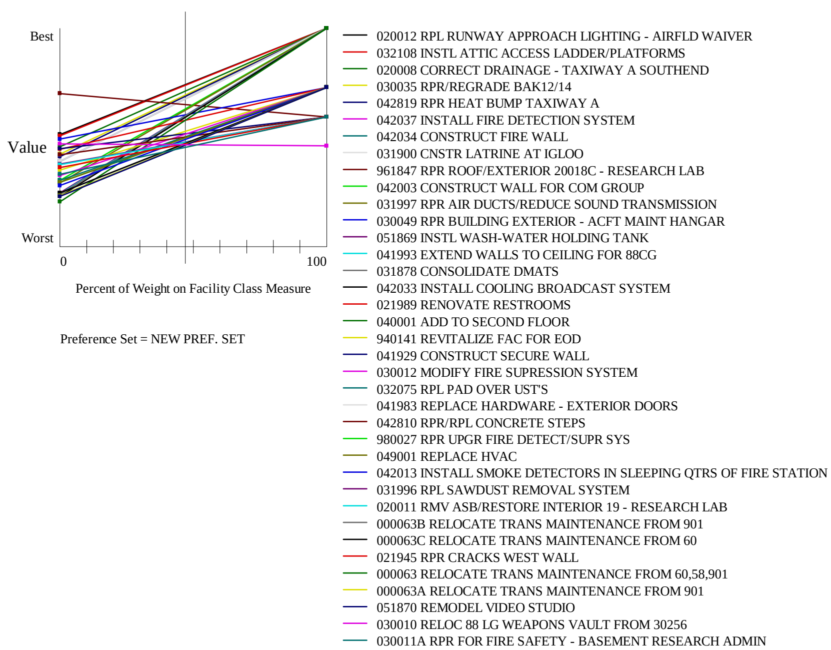


**Figure 24.  Sensitivity Analysis for Funding Strategy 1 - Facility Class**

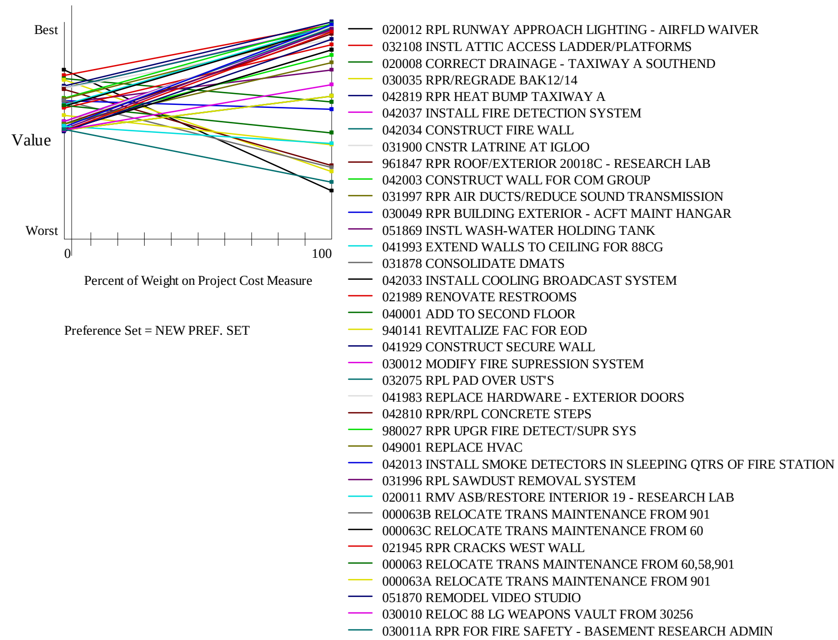


**Figure 25. Sensitivity Analysis for Funding Strategy 1 - Project Cost**

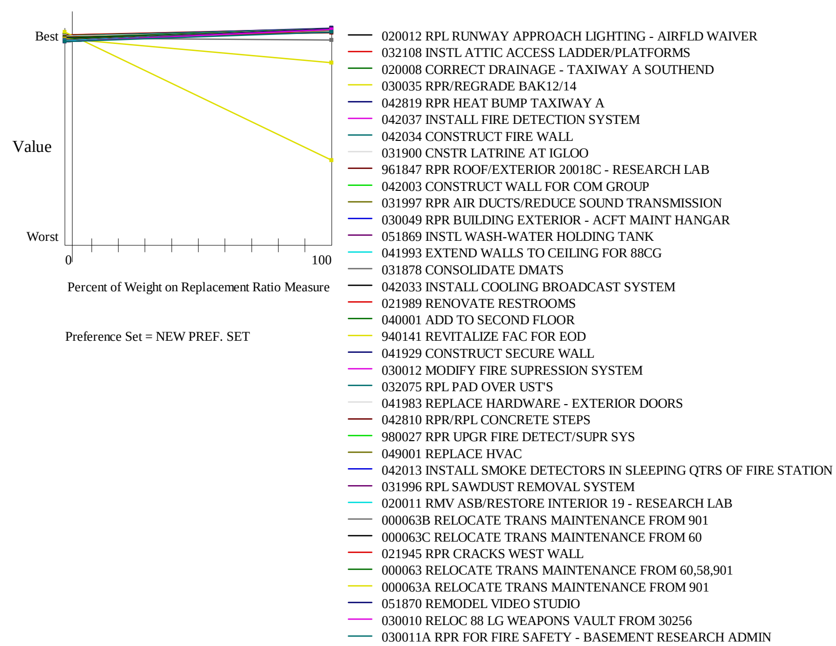


**Figure 26. Sensitivity Analysis for Funding Strategy 1 - Replacement Ratio**

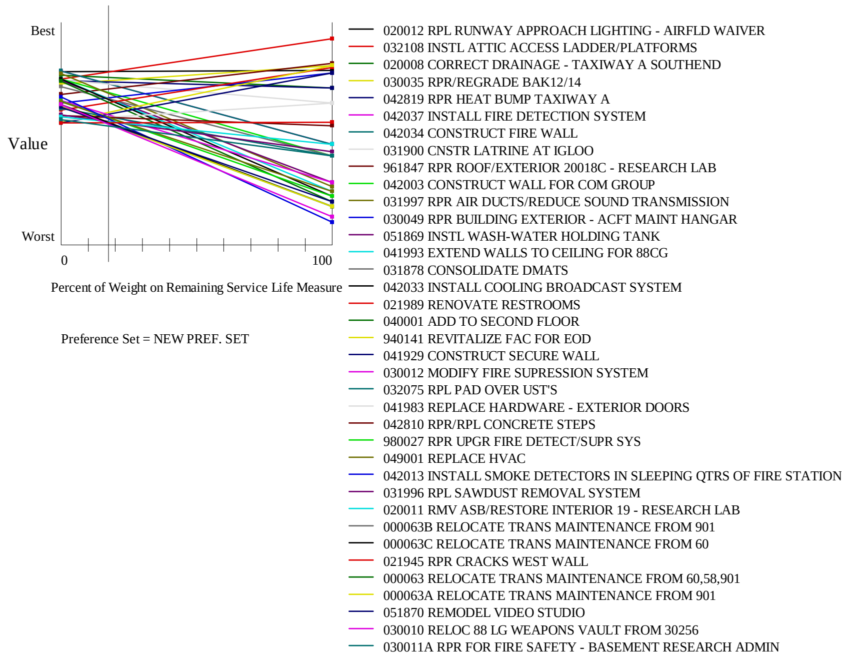


**Figure 27. Sensitivity Analysis for Funding Strategy 1 - Remaining Service Life**

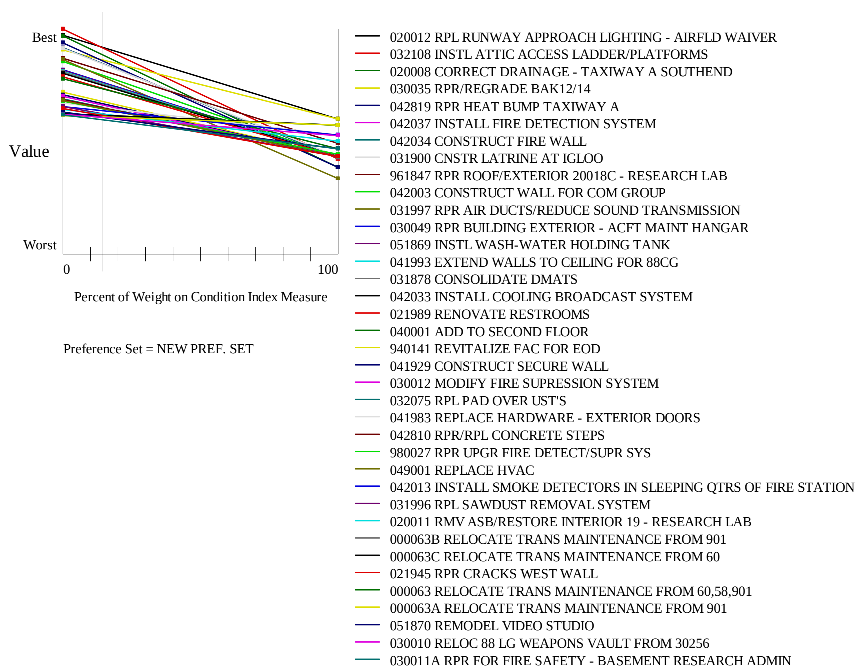


**Figure 28. Sensitivity Analysis for Funding Strategy 1 - Condition Index**

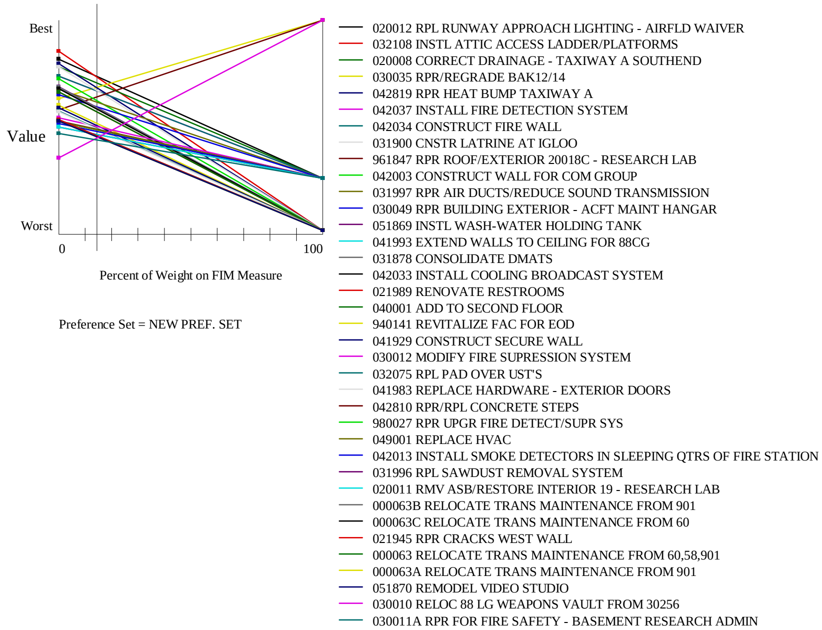


**Figure 29. Sensitivity Analysis for Funding Strategy 1 – FIM**

## Funding Strategy 2: Overall Improvement by Mission Impact

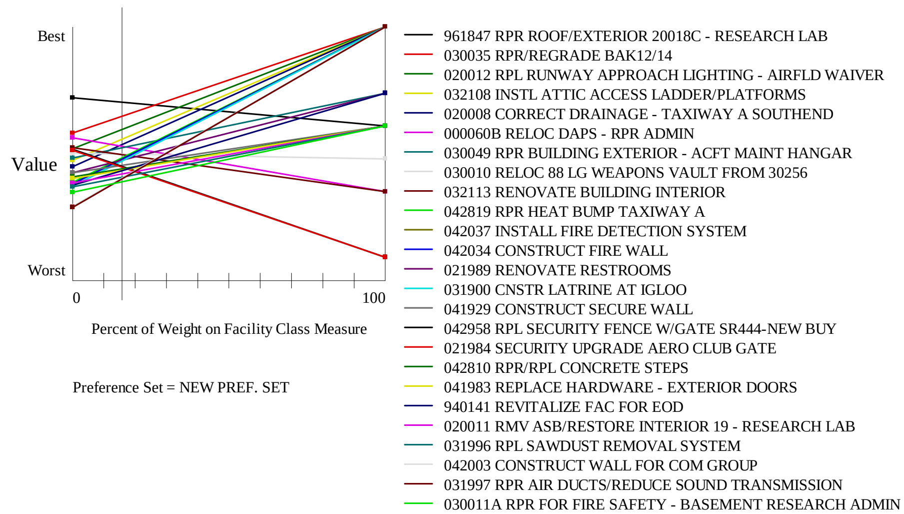


**Figure 30. Sensitivity Analysis for Funding Strategy 2 - Facility Class**

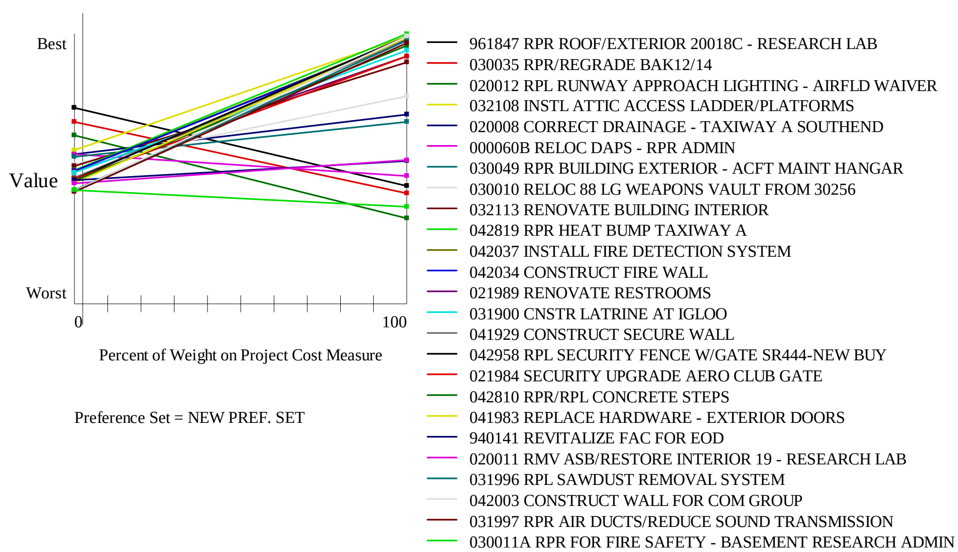


**Figure 31. Sensitivity Analysis for Funding Strategy 2 - Project Cost**

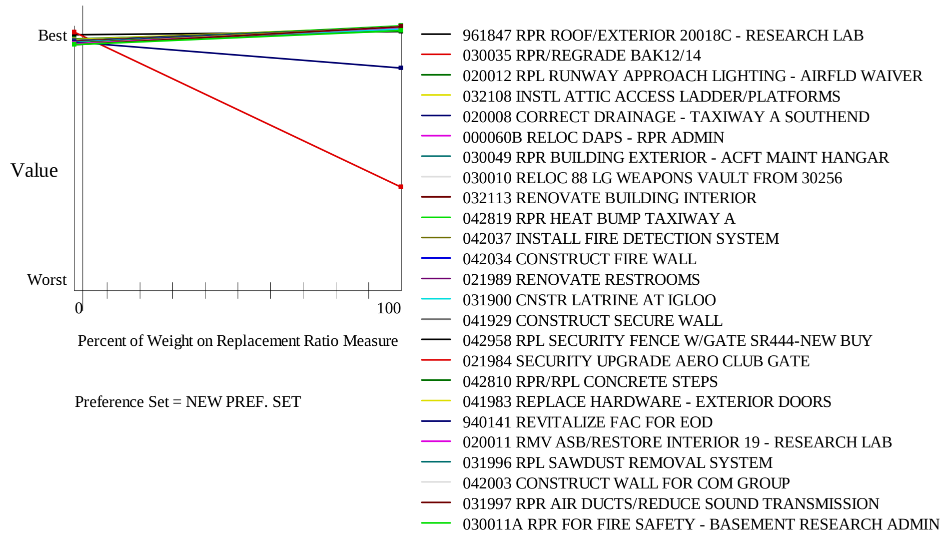


**Figure 32. Sensitivity Analysis for Funding Strategy 2 - Replacement Ratio**

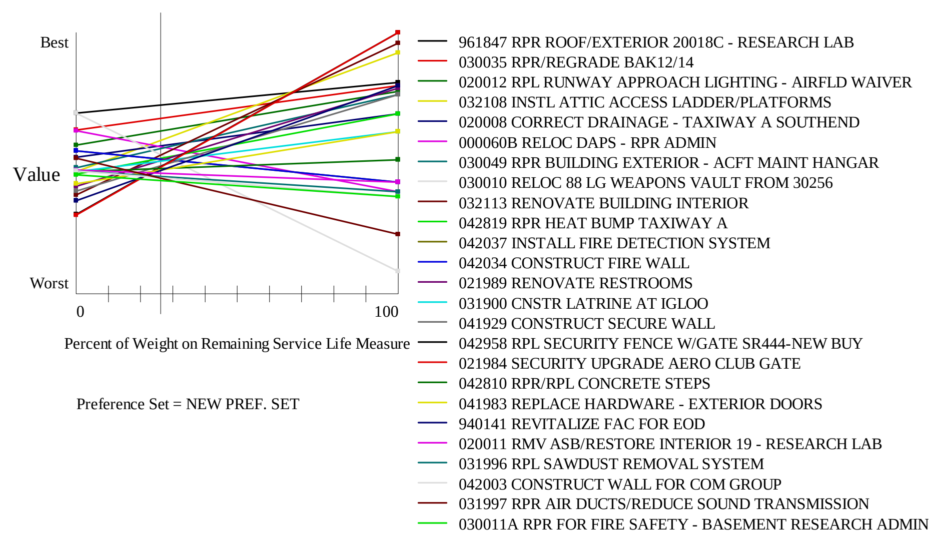


**Figure 33. Sensitivity Analysis for Funding Strategy 2 - Remaining Service Life**

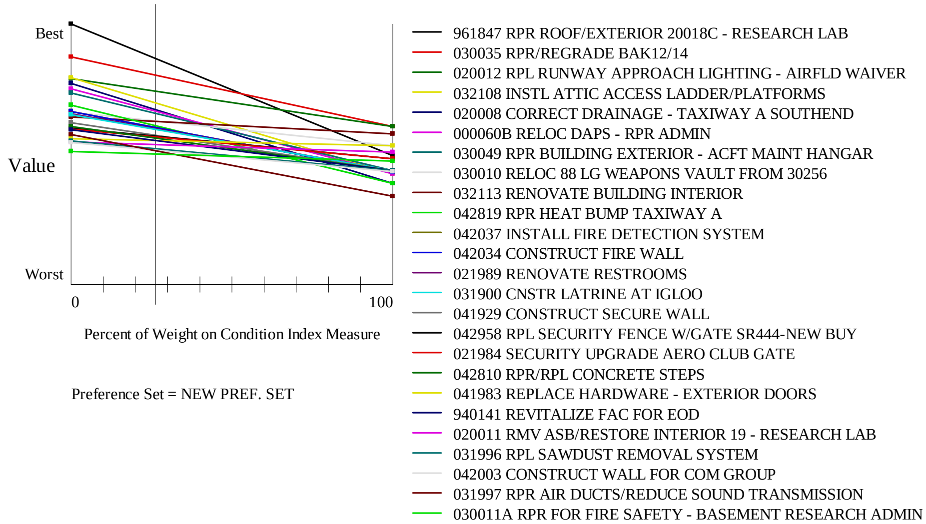


**Figure 34. Sensitivity Analysis for Funding Strategy - Condition Index**

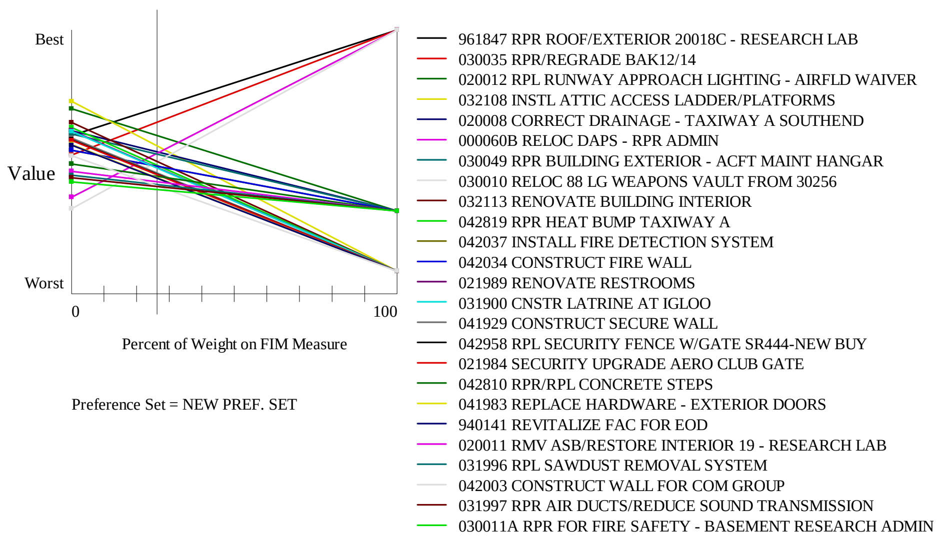


**Figure 35. Sensitivity Analysis for Funding Strategy**

## Funding Strategy 3: Minimize Degradation

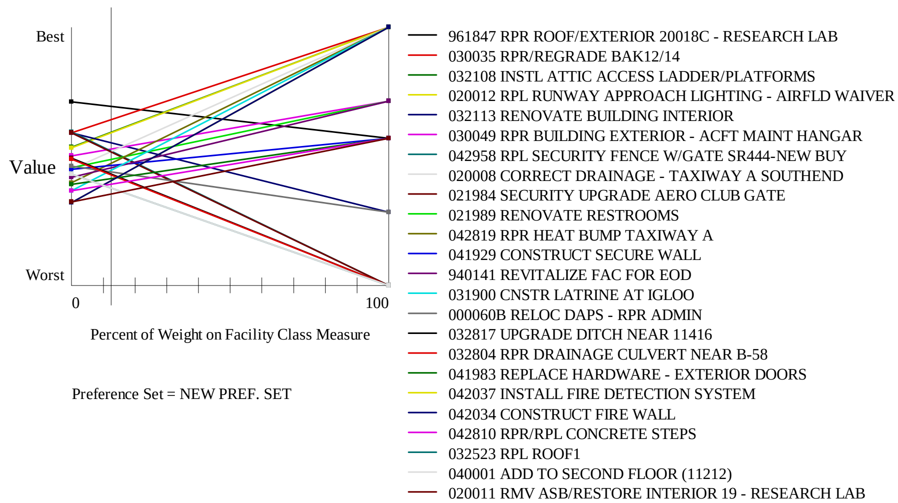


**Figure 36. Sensitivity Analysis for Funding Strategy 3 - Facility Class**

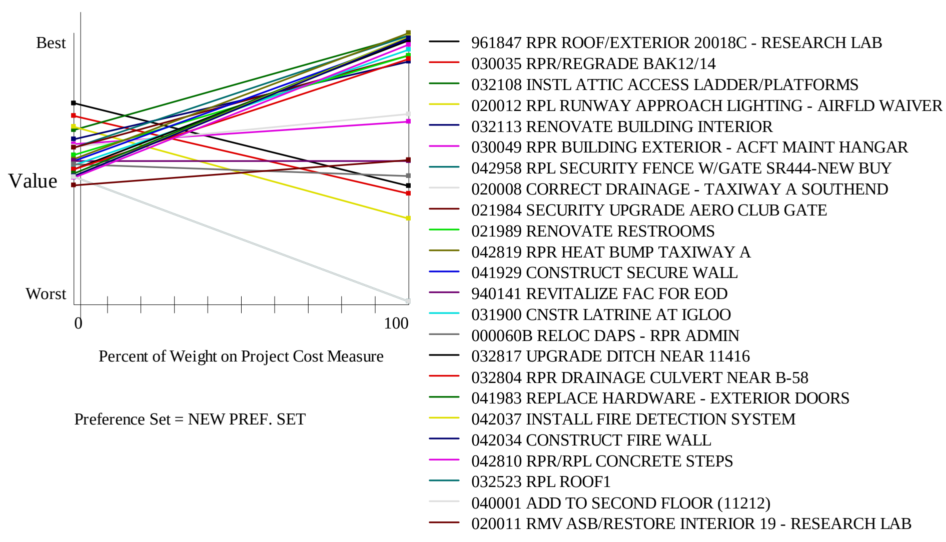


**Figure 37. Sensitivity Analysis for Funding Strategy 3 - Project Cost**

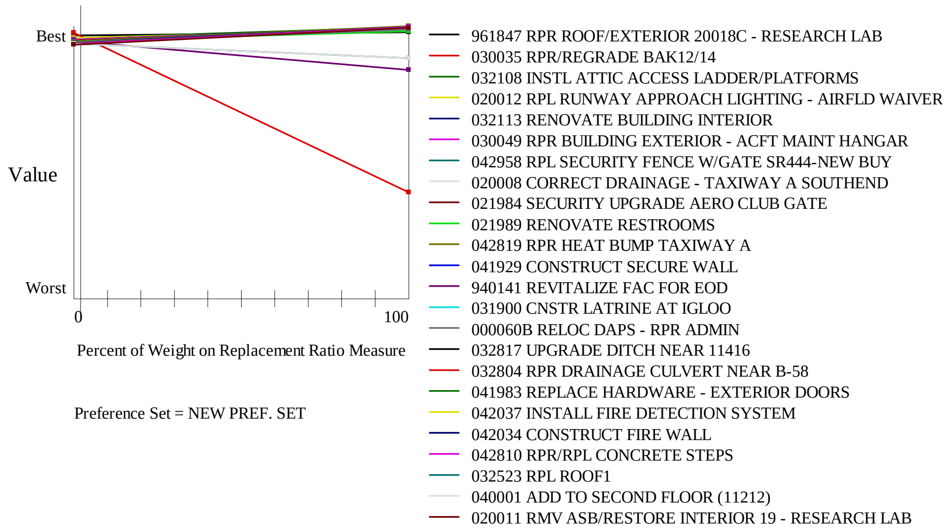


**Figure 38. Sensitivity Analysis for Funding Strategy 3 - Replacement Ratio**

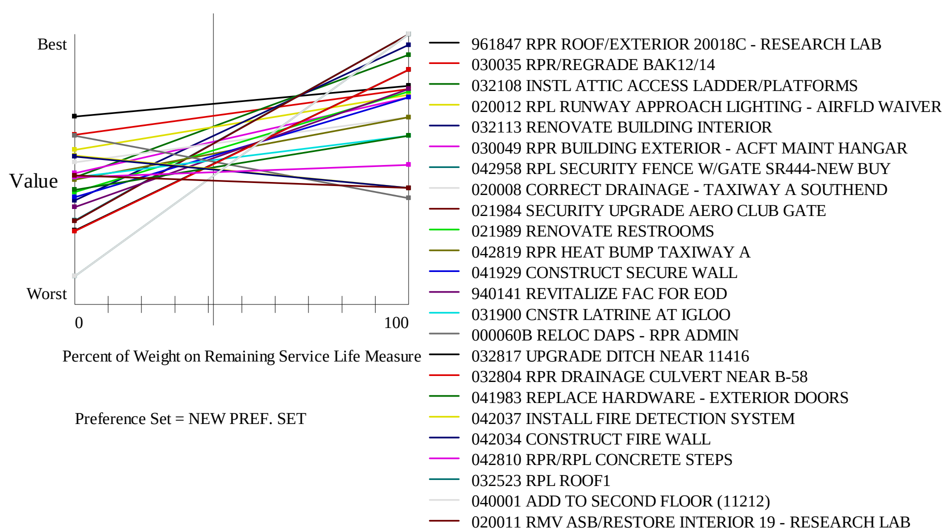


**Figure 39. Sensitivity Analysis for Funding Strategy 3 - Remaining Service Life**

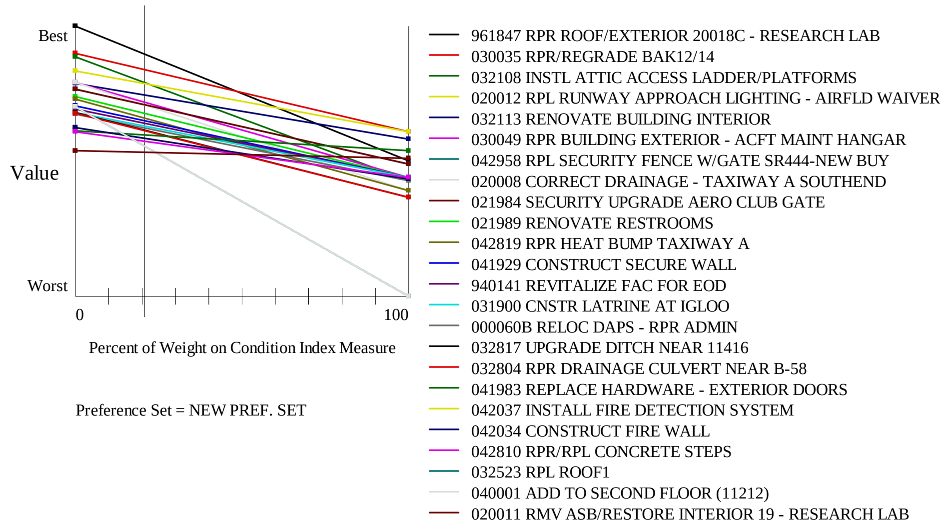


**Figure 40. Sensitivity Analysis for Funding Strategy 3 - Condition Index**

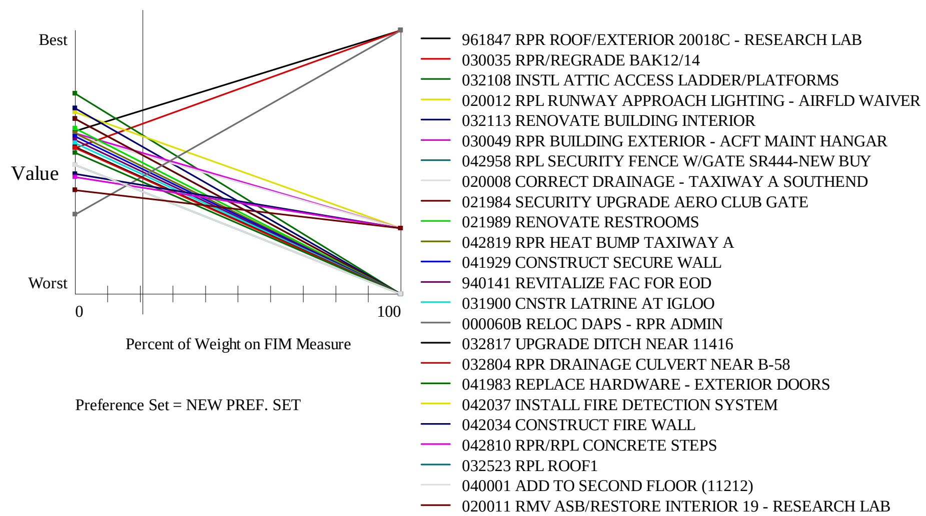


**Figure 41. Sensitivity Analysis for Funding Strategy 3 - FIM**

# Appendix D. Impact to Service Life Based on Renovation Fraction

## Table 6. Impact to Service Life based on Renovation Fraction

| Project Number | Project Title | Renovation Fraction | FUNDING STRATEGIES | | |
|---|---|---|---|---|---|
| | | | Attributes | Mission Impact | Minimize Degradation |
| ZHTV030035 | RPR/REGRADE BAK12/14 - AIRFIELD WAIVER * | 0.031 | 0.031 | 0.031 | 0.031 |
| ZHTV020012 | RPL RUNWAY APPROACH LIGHTING - AIRFLD WAIVER | 0.102 | 0.102 | 0.102 | 0.102 |
| ZHTV040001 | ADD TO SECOND FLOOR (11212) | 0.5 | 0.5 | | 0.5 |
| ZHTV020008 | CORRECT DRAINAGE - TAXIWAY A SOUTHEND | 0.061 | 0.061 | 0.061 | 0.061 |
| ZHTV031900 | CNSTR LATRINE AT IGLOO | 0.013 | 0.013 | 0.013 | 0.013 |
| ZHTV021989 | RENOVATE RESTROOMS | 0.011 | 0.011 | 0.011 | 0.011 |
| ZHTV031878 | CONSOLIDATE DMATS | 0.5 | 0.5 | | |
| ZHTV042003 | CONSTRUCT WALL FOR COM GROUP | 0.078 | 0.078 | 0.078 | |
| ZHTV032108 | INSTL ATTIC ACCESS LADDER/PLATFORMS | 0.001 | 0.001 | 0.001 | 0.001 |
| ZHTV041993 | EXTEND WALLS TO CEILING FOR 88CG | 0.078 | 0.078 | | |
| ZHTV031997 | RPR AIR DUCTS/REDUCE SOUND TRANSMISSION | 0.047 | 0.047 | 0.047 | |
| ZHTV042033 | INSTALL COOLING FOR BROADCAST SYSTEM | 0.053 | 0.053 | | |
| ZHTV051869 | INSTL WASH-WATER HOLDING TANK | 0.009 | 0.009 | | |
| ZHTV042819 | RPR HEAT BUMP TAXIWAY A -NEW BUY | 0.012 | 0.012 | 0.012 | 0.012 |
| ZHTV961847 | RPR ROOF/EXTERIOR 20018C - RESEARCH LAB | 0.188 | 0.188 | 0.188 | 0.188 |
| ZHTV042037 | INSTALL FIRE DETECTION SYSTEM | 0.001 | 0.001 | 0.001 | 0.001 |
| ZHTV042034 | CONSTRUCT FIRE WALL | 0.001 | 0.001 | 0.001 | 0.001 |
| ZHTV030049 | RPR BUILDING EXTERIOR - ACFT MAINT HANGAR | 0.149 | 0.149 | 0.149 | 0.149 |
| ZHTV940141 | REVITALIZE FAC FOR EOD | 0.5 | 0.5 | 0.5 | 0.5 |
| ZHTV030012 | MODIFY FIRE SUPRESSION SYSTEM | 0.019 | 0.019 | | |
| ZHTV041929 | CONSTRUCT SECURE WALL | 0.2 | 0.2 | 0.2 | 0.2 |
| ZHTV042810 | RPR/RPL CONCRETE STEPS | 0.09 | 0.09 | 0.09 | 0.09 |
| ZHTV041983 | REPLACE HARDWARE - EXTERIOR DOORS | 0.034 | 0.034 | 0.034 | 0.034 |
| ZHTV032075 | RPL PAD OVER UST'S | 0.07 | 0.07 | | |
| ZHTV980027 | RPR UPGR FIRE DETECT/SUPR SYS | 0.016 | 0.016 | | |
| ZHTV049001 | REPLACE HVAC (12140) | 0.053 | 0.053 | | |
| ZHTV031996 | RPL SAWDUST REMOVAL SYSTEM | 0.004 | 0.004 | 0.004 | |
| ZHTV042013 | INSTALL SMOKE DETECTORS IN SLEEPING QTRS OF FIRE STATION | 0.003 | 0.003 | | |
| ZHTV020011 | RMV ASB/RESTORE INTERIOR 18 - RESEARCH LAB | 0.15 | 0.15 | 0.15 | 0.15 |
| ZHTV021945 | RPR CRACKS WEST WALL | 0.099 | 0.099 | | |

| Project Number | Project Title | Renovation Fraction | FUNDING STRATEGIES | | |
|---|---|---|---|---|---|
| | | | Attributes | Mission Impact | Minimize Degradation |
| ZHTV000063 | RELOCATE TRANS MAINTENANCE FROM 60,58,901 | 0.5 | 0.5 | | |
| ZHTV000063A | RELOC TRANS MAINT FROM 901 | 0.5 | 0.5 | | |
| ZHTV000063B | RELOC TRANS MAINT FROM 901 | 0.5 | 0.5 | | |
| ZHTV000063C | RELOCATE TRANS MAINT FROM 60 | 0.5 | 0.5 | | |
| ZHTV051870 | REMODEL VIDEO STUDIO W156 | 0.5 | 0.5 | | |
| ZHTV030011A | RPR FOR FIRE SAFETY - BASEMENT RESEARCH ADMIN * | 0.017 | 0.017 | 0.017 | |
| ZHTV030010 | RELOC 88 LG WEAPONS VAULT FROM 30256 | 0.5 | 0.5 | 0.5 | |
| ZHTV000060B | RELOC DAPS - RPR ADMIN | 0.5 | 0.5 | 0.5 | 0.5 |
| ZHTV042958 | RPL SECURITY FENCE W/GATE SR444-NEW BUY | 0.002 | | 0.002 | 0.002 |
| ZHTV021984 | SECURITY UPGRADE AERO CLUB GATE | 0.002 | | 0.002 | 0.002 |
| ZHTV032113 | RENOVATE BUILDING INTERIOR | 0.108 | 0.108 | 0.108 | 0.108 |
| ZHTV040203A | CONSOLIDATE SPO FROM 20016 | 0.5 | | 0.5 | 0.5 |
| ZHTV032804 | RPR DRAINAGE CULVERT NEAR B-58 | 0.063 | | | 0.063 |
| ZHTV032817 | UPGRADE DITCH NEAR 11416 | 0.013 | | | 0.013 |
| ZHTV032523 | RPL ROOF | 0.039 | | | 0.039 |
| **Total Potential for Extending Service Life:** | | | **6.698** | **3.302** | **3.271** |

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## Vita

Captain Mona A. Tenorio graduated from Kaiserslautern American High School, Germany. She entered the undergraduate program at the California State University, Sacramento where she graduated with a Bachelor of Science degree in Civil Engineering in May 1996. She was also commissioned through Detachment 088 AFROTC where she was recognized as a Distinguished Graduate and nominated for a Regular Commission.

Her first assignment was at Beale AFB in July 1996 where she served as a Design Civil Engineer and Chief of SABER. In June 2000, she was assigned to the 554$^{th}$ RED HORSE Squadron, Osan AB, South Korea where she served as a Project Engineer. Her next assignment was to the 86$^{th}$ Civil Engineer Squadron, Ramstein Air Base as the Chief of Environmental Compliance. She then transferred to the 786$^{th}$ Civil Engineer Squadron and served at the Maintenance Engineering Flight Commander. In August 2003, she entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, she will be assigned to the staff at Headquarters Air Combat Command Inspector General, Langley AFB, Virginia.

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**14. ABSTRACT**

Infrastructure systems and facilities have deteriorated due to the impact of limited defense funding and competing priorities within the Air Force. The current method used for infrastructure prioritization is influenced by political sensitivity and uncertainty regarding the consequences of various funding decisions. Senior leaders need to better understand how their funding decisions will impact the overall condition and service life of the installation's infrastructure systems and facilities.

The purpose of this research was to improve the method of prioritizing infrastructure projects through the use of a decision analysis methodology known as Value-Focused Thinking. The value model was created based on the perspective of the civil engineer with inputs from a proxy decision maker at Headquarters Air Force Materiel Command. The model was used to apply three funding strategies to develop prioritized lists of restoration and modernization projects. It also applies metrics to compare the three funding strategies and their impact to the installation's infrastructure. The resulting model provides insight to the decision maker on which funding strategy is best suited for prioritizing infrastructure projects and how their selection of prioritized projects will impact the overall condition and service life of infrastructure systems and facilities.

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